

CEPHEID VARIABLES IN THE MASER-HOST GALAXY NGC 4258

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ABSTRACT

We present results of a ground-based survey for Cepheid variables in NGC 4258. This galaxy plays a key role in the Extragalactic Distance Scale due to its very precise and accurate distance determination via VLBI observations of water masers. We imaged two fields within this galaxy using the Gemini North telescope and GMOS, obtaining 16 epochs of data in the SDSS *gri* bands over 4 years. We carried out PSF photometry and detected 94 Cepheids with periods between 7 and 127 days, as well as an additional 215 variables which may be Cepheids or Population II pulsators. We used the Cepheid sample to test the absolute calibration of theoretical *gri* Period-Luminosity relations and found good agreement with the maser distance to this galaxy. The expected data products from the Large Synoptic Survey Telescope (LSST) should enable Cepheid searches out to at least 10 Mpc.

Subject headings: stars: variables: Cepheids; galaxies: indiv. (NGC 4258); cosmology: distance scale

1. INTRODUCTION

The classical Extragalactic Distance Scale plays a key role in the current era of “precision cosmology” by providing an estimate of the Hubble constant (H_0) free from assumptions about the contents of our Universe. Hence, comparing the value of H_0 obtained via Cepheids and type Ia supernovae (e.g., Riess et al. 2011) with the one inferred from BAO and CMB observations (Anderson et al. 2014; Planck Collaboration et al. 2013) can provide a strong additional constraint on the properties of dark energy and other cosmological parameters (Weinberg et al. 2013; Dvorkin et al. 2014).

NGC 4258 is a critical anchor in the Cosmic Distance Ladder thanks to its very precise and accurate distance estimate based on VLBI observations of water masers orbiting its central massive black hole (Miyoshi et al. 1995; Herrnstein et al. 1999; Argon et al. 2007; Humphreys et al. 2008), with a current value of $D = 7.6 \pm 3\%$ Mpc (Humphreys et al. 2013, equivalent to a distance modulus of $\mu_0 = 29.404 \pm 0.065$ mag). It was previously surveyed for Cepheids by Macri et al. (2006), who used the *Hubble Space Telescope* Advanced Camera for Surveys (ACS) to discover 281 variables with periods between 4 and 45 days. Recently, Fausnaugh et al. (2014) used the Large Binocular Telescope to survey the entire disk of NGC 4258 for Cepheids and found 81 Cepheids with $13 < P < 90$ d. They used the technique developed by Gerke et al. (2011), in which Cepheids are detected via difference-imaging of ground-based data and the photometric calibration is obtained from *Hubble* images.

Given the importance of NGC 4258 for the Extragalactic Distance Scale, we wished to increase its sample of Cepheids with an emphasis on long-period objects. Among the 117 NGC 4258 Cepheids used by Riess et al. (2011), only 24% have $P > 30$ d (11% for $P > 40$ d), whereas the samples in the 8 SNe Ia hosts used in that work contain 72% and 47% of the objects in the same

period ranges. A better match in the period range spanned by calibrator and target galaxies helps to decrease the impact of the systematic uncertainty associated with possible changes in the slope of the Cepheid Period-Luminosity (P-L) relation from galaxy to galaxy. An additional motivation for our study was to provide an empirical absolute calibration of the Cepheid Period-Luminosity relations in the SDSS *gri* filters, to supplement the semi-empirical approach of Ngeow & Kanbur (2007) and the theoretical models of Di Criscienzo et al. (2013). The use of this filter set for Cepheid work will become more prevalent in the era of LSST.

The rest of this paper is organized as follows: §2 presents the details of the observations; §3 describes the data reduction, photometry and calibration; §4 discusses the fiducial Cepheid P-L relations in the SDSS filters; §5 details the procedures used to identify and classify Cepheid variables; §6 discusses our results; and §7 explores the use of LSST for extragalactic Cepheid work.

2. OBSERVATIONS

2.1. Gemini North

We conducted the Cepheid search using the Gemini North 8.1-m telescope and the Gemini Multi-Object Spectrograph (GMOS, Davies et al. 1997), under programs GN-2004A-Q-22 and GN-2007A-Q-14. GMOS has a $5'5 \times 5'5$ field of view that is covered by three charged-coupled devices (CCDs) with a scale of $0''.0727/\text{pixel}$. There are two small ($2''.8$) gaps between the CCDs and the corners of the outer chips are not illuminated.

NGC 4258 was imaged on 22 nights over 4 years in order to ensure good phase coverage of the Cepheids. We targeted two fields within the galaxy located at different galactocentric distances, placed so they would fully contain the regions previously observed by Macri et al. (2006). The GMOS field of view is $\sim 3\times$ that of ACS, so this overlap enables the recovery of long-period Cepheids previously discovered with HST while still significantly extending the area of the disk that is monitored for variables. We follow the naming convention adopted

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TABLE 1
OBSERVATION LOG

Date	Images
2004 Feb 18	$g \times 2, r \times 2, i \times 2$ (I,O)
2004 Feb 20	$g \times 2$ (I,O); $r \times 2, i \times 2$ (I)
2004 Mar 29	$g \times 2$ (O)
2004 May 22	$g \times 2$ (I), $\times 3$ (O) $r \times 2, i \times 2$ (I,O)
2004 May 24	$g \times 2, r \times 2, i \times 2$ (I,O)
2004 Jul 08	$g \times 2, r \times 2, i \times 2$ (I)
2004 Jul 14	$r \times 1, i \times 2$ (O)
2005 Feb 10	$g \times 2, r \times 2, i \times 2$ (I,O)
2005 Mar 09	$g \times 2, r \times 2, i \times 2$ (I,O)
2005 Apr 09	$g \times 2, r \times 2, i \times 2$ (I,O)
2005 Apr 12	$g \times 2, r \times 2, i \times 2$ (I,O)
2005 May 04	$g \times 2, r \times 2, i \times 2$ (I,O)
2005 May 08	$g \times 2, r \times 2, i \times 2$ (I,O)
2007 Feb 22	$g \times 2, r \times 2, i \times 2$ (I,O)
2007 Apr 07	$r \times 2, i \times 1$ (O)
2007 Apr 12	$g \times 2, r \times 2, i \times 2$ (I,O)
2007 Apr 20	$g \times 2, r \times 2, i \times 2$ (O)
2008 Jan 06	$g \times 2, r \times 2, i \times 2$ (I)
2008 Jan 07	$g \times 2, r \times 2, i \times 2$ (O)
2008 Jan 10	$g \times 2, r \times 2, i \times 2$ (I)
2008 Jan 16	$g \times 3, r \times 2, i \times 2$ (O)
2008 Feb 16	$g \times 2, r \times 2, i \times 2$ (I)

NOTE. — I: inner field; O: outer field.

by Macri et al. (2006): the field located at a larger galactocentric distance is called “outer” and the one closer to the galaxy nucleus is called “inner”. The GMOS fields were centered at $\alpha = 12^{\text{h}}19^{\text{m}}20.16^{\text{s}}, \delta = +47^{\circ}12'33''.3$ and $\alpha = 12^{\text{h}}18^{\text{m}}48.21^{\text{s}}, \delta = +47^{\circ}20'25''.8$ (J2000.0) for the “outer” and “inner” fields respectively. Figure 1 shows the location of the fields within the galaxy.

We typically obtained 2×600 s exposures at each epoch using the Sloan Digital Sky Survey (SDSS) *gri* filters (Fukugita et al. 1996). The observations were obtained in queue mode by Gemini staff when the sky conditions were clear (although not necessarily photometric) and the seeing was below $0''.7$; 16 useful epochs were obtained for each field. The observation log is presented in Table 1.

2.2. WIYN

In order to perform a photometric calibration of the Gemini data (see §3.3), additional observations were obtained with the 3.5-m WIYN telescope at Kitt Peak National Observatory using the MiniMosaic camera. Its field of view of $9''.6 \times 9''.6$ is covered by 2 CCDs. The camera was used in 2×2 binned mode, which yields an effective scale of $0''.28/\text{pixel}$. We observed ten fields covering NGC 4258 at three different epochs (one night per lunation for three consecutive months) using SDSS *gri* filters (Kitt Peak filter numbers k1017, k1018, k1019). The location of the fields is outlined in gray (blue in online edition) in Figure 1. An additional four fields covering M67 were observed to derive accurate color transformations. Exposure times of 30 s, 300 s and 600 s (hereafter, “shallow”, “medium” and “deep”) were chosen to bridge the magnitude gap between SDSS and our Gemini photometry.

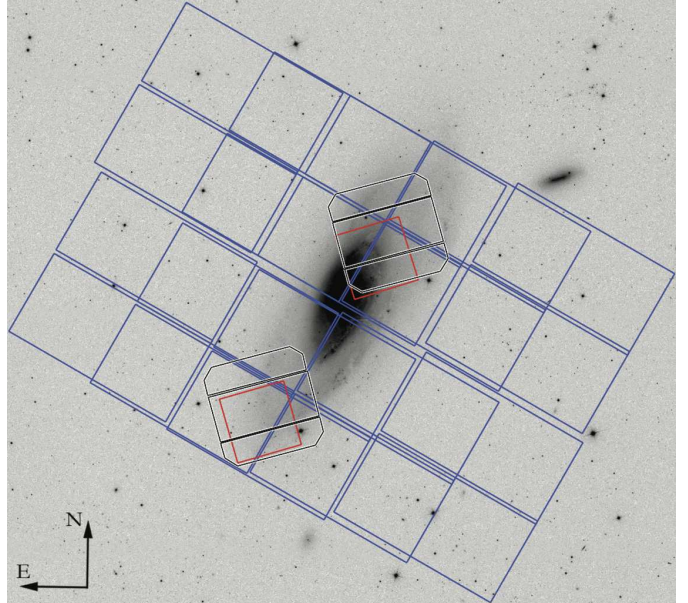


FIG. 1.— SDSS *r*-band mosaic ($36' \times 32'$) of NGC 4258 showing the footprints of the GMOS (octagonal, black and white), WIYN (square, blue) and Macri et al. (2006) HST/ACS (square, red) fields. The “inner” field is located north of the galaxy center, while the “outer” field is located south and east.

3. DATA REDUCTION AND PHOTOMETRY

3.1. Gemini

We processed the raw images using the IRAF² *gemini* package. These routines perform overscan, bias and flat-field corrections that take into account the unique field of view of GMOS. Each CCDs was extracted to a separate FITS file, and the edges were trimmed by an additional 50 pixels.

Due to the crowded nature of the fields, we carried out point-spread function (PSF) photometry using the DAOPHOT and ALLSTAR programs (Stetson 1987, 1993) on each image. Through visual inspection of the images using IRAF, we derived a starting value for the PSF FWHM of 5 pixels with a local sky annulus extending from 15 to 20 pixels. The task FIND was used for an initial detection of objects above a 5σ while the PHOT task returned aperture photometry for these objects. Stars at or near the saturation limit and objects within $2-5''$ were identified and temporarily removed from the photometry files to ensure they were not used in the calculation of the PSF model. Saturation trails were masked in a similar manner. The PICK task was used to select 100 stars from the cleaned aperture photometry list, which were visually examined to confirm that they were bright and isolated and to reject misidentified galaxies and stars with close companions. About 15-35 stars per chip remained after this examination, which were used by the PSF task to calculate a PSF model for each image. Finally, ALLSTAR was run to obtain preliminary PSF photometry for all sources.

We used DAOMATCH and DAOMASTER to calculate coor-

² IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

TABLE 2
PHOTOMETRIC CALIBRATION STEPS

Step	Reference	Target	Mag. range			N stars	σ [mmag]		
			g	r	i		g	r	i
WIYN/MiMo color term	SDSS-DR7 cat	M67	13–21	12–20		345	2	2	1
WIYN/MiMo zeropoint	SDSS-DR7 cat	N4258 “shallow”	14–20	13–19	14–19	79	4	6	9
WIYN/MiMo transfer	N4258 “shallow”	N4258 “deep”		16–21		70	20	21	30
Gem./GMOS-N color term	Adopted from Jørgensen (2009)					...	1	2	3
Gem./GMOS-N zeropoint	N4258 “deep”	GMOS inner/outer		21–24		101	38	33	32
Total							43	40	45

NOTE. — Systematic uncertainties associated with color terms are evaluated at the extreme ranges of Cepheid colors. All quoted values are averages over different CCDs; actual values were propagated for the Cepheid photometry.

dinate transformations between the images. We selected 7 or 8 images with the best seeing to create a master image in each band and chip. We performed photometry on each master frame as described above, but this time adopting a 3σ threshold. The total number of objects detected was $\sim 4 \times 10^4$, 6×10^4 and 7×10^4 in gri respectively. Lastly, ALLFRAME (Stetson 1994) was used to carry out fixed-position, simultaneous PSF photometry on all images.

3.2. WIYN

We applied an overscan, bias and flat-field correction on all images obtained at the WIYN telescope using the IRAF `mscared` package. We performed PSF photometry on all images using the DAOPHOT package as described in the previous section. We selected bright, isolated stars to create a PSF model for each image and ALLSTAR was run to obtain PSF photometry.

3.3. Photometric Calibration

Due to the significant difference in the magnitude range covered by the SDSS-DR7 photometric catalog (Abazajian et al. 2009) and our Gemini images, it was not possible to obtain a direct calibration of the latter based on the former. Bright stars in the Gemini images were undetected by SDSS, while most bright SDSS stars were saturated in the Gemini fields. We bridged this magnitude gap by observing the NGC 4258 fields with WIYN as described in §2.2 and generating a catalog of local standards.

All steps in our photometric calibration procedure are listed in Table 2. We describe the term being solved for, the source and target photometric catalogs, magnitude range of the stars being used, number of objects used in the final fit, and the systematic uncertainty to be propagated into our final Cepheid magnitudes. In the case of color terms, we evaluated the uncertainty at the extremes of the color range spanned by Cepheids (± 0.5 mag relative to the pivot color used in our solutions). In all cases we used PSF photometry and parameters were determined through an iterative sigma clipping procedure. We visually inspected all objects being used in any step that tied two different telescopes/cameras to remove galaxies and blends. Some comments on the individual steps follow.

We found small but well-detected color terms for the transformation of WIYN MiniMosaic magnitudes into the SDSS system; using $g-r$ as the target color, the values were -0.038 , -0.032 , -0.037 ± 0.003 for gri , respectively. These were derived using high SNR obser-

vations of M67 and were fixed for the subsequent step (determination of zeropoints for the “shallow” NGC 4258 fields). Table 3 lists the magnitudes of these secondary standards, which may be useful to future observers. Due to the limited color range of the stars in common between WIYN and Gemini, and their noisier photometry (median $\sigma = 0.045$ mag), we adopted the color terms for GMOS-N derived by Jørgensen (2009) and only solved for the zeropoints. We listed the mean uncertainties for this step in the Table, but propagated the actual values in our calculations. In summary, we estimate systematic zeropoint uncertainties of ~ 45 mmag for our Cepheid magnitudes.

We carried out artificial star tests to characterize the completeness and crowding biases in the Gemini photometry. We divided the color-magnitude diagram into four quadrants and randomly selected 30 stars from each one to ensure that a broad range of stars were simulated. We added these 120 stars to the master frame with the DAOPHOT task ADDSTAR. We repeated this procedure 20 times to increase the statistical significance of our simulations. We performed photometry and matched the detected objects with the input artificial star lists, adopting a critical matching radius of 1.1 pix (equivalent to 3σ). Table 4 lists the magnitudes at which we expect to detect 50% and 80% of the sources. We found no statistically significant photometric bias due to crowding at the magnitudes equivalent to 50% completeness levels. Given the maser distance to NGC 4258 and the fiducial P-L relations discussed in §4, we expect our Cepheid sample to be severely incomplete below $P = 10$ and 15d for the outer and inner fields, respectively.

Before discussing the identification of Cepheid variables in our data, we will address the issue of fiducial Cepheid P-L relations in the SDSS filters since these are used in our candidate selection process.

4. FIDUCIAL CEPHEID P-L RELATIONS IN SDSS FILTERS

Despite its introduction nearly two decades ago, the SDSS filter set has rarely been used for Cepheid photometry. The two most notable uses are the massive surveys of M33 (Hartman et al. 2006) and M31 (Kodric et al. 2013, 2014) using the MMT and the Pan-STARRS telescopes, respectively. Unfortunately, despite concerted efforts over the past decade (Ribas et al. 2005; Bonanos et al. 2006; Vilardell et al. 2010) neither galaxy has a distance estimate as robust as that for the LMC by Pietrzyński et al. (2013): $D = 49.97 \pm 2\%$ kpc (equivalent to $\mu_0 = 18.493 \pm 0.048$ mag). Furthermore, given the apparent LMC-like metallicity prevalent throughout most

TABLE 3
SECONDARY STANDARDS

RA [deg, J2000]	Dec.	Magnitudes			σ [mmag]			Used in
		<i>g</i>	<i>r</i>	<i>i</i>	<i>g</i>	<i>r</i>	<i>i</i>	
184.39152	47.24800	16.764	16.256	16.141	3	6	6	SW
184.39327	47.25668	20.676	19.296	18.628	6	7	7	SW
184.39842	47.22298	19.955	19.497	19.290	10	18	18	SW
184.42695	47.24926	19.917	18.898	18.552	4	4	4	SW
184.43053	47.22627	19.986	19.540	19.388	5	9	9	SW

NOTE. — SW: used in SDSS-WIYN calibration; WG: used in WIYN-Gemini calibration. This table is available in its entirety in machine-readable form in the online version of the paper. A portion is shown here for guidance regarding its form and content.

TABLE 4
PHOTOMETRIC COMPLETENESS LIMITS

Field	80% completeness			50% completeness		
	<i>g</i>	<i>r</i>	<i>i</i>	<i>g</i>	<i>r</i>	<i>i</i>
Inner	24.7	25.0	24.2	25.9	25.5	24.9
Outer	25.2	25.1	24.5	26.1	25.7	25.3

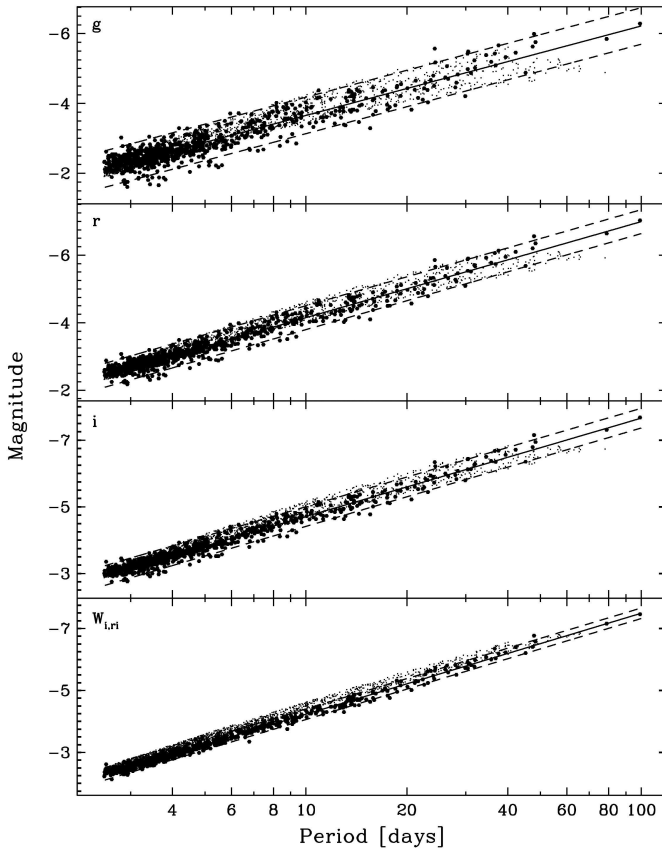


FIG. 2.— Fiducial Cepheid P-L relations in the SDSS *gri* bands (top to bottom). Filled symbols denote LMC Cepheids, transformed from *VI* to *gri* using the procedure described in §4, while dots represent theoretical Cepheid magnitudes from Di Criscienzo et al. (2013). The solid line represents the best fit to the LMC data while the dashed lines indicate the $\pm 2\sigma$ width of the relations.

of the disk of NGC 4258 (Bresolin 2011), this Milky Way satellite should provide the most appropriate sample of Cepheids from which to obtain a fiducial P-L relation for our analysis.

Motivated by the above, and in a manner similar to previous work by Ngeow & Kanbur (2007), we generated semi-empirical Cepheid P-L relations in the SDSS *gri* filters based on *VI* photometry for > 750 LMC variables with $2.5 < P < 100$ d compiled by Macri et al. (2014). This dataset consists mainly of OGLE photometry Soszynski et al. (2008); Ulaczyk et al. (2013) supplemented by literature measurements for additional long-period objects (Martin et al. 1979; Freedman et al. 1985; Barnes et al. 1999; Tanvir & Boyle 1999; Sebo et al. 2002; Ngeow & Kanbur 2006). We derived photometric transformations appropriate for Cepheids using synthetic magnitudes for stars with $\log g \leq 1$ based on the Castelli & Kurucz (2003) models, kindly provided by F. Castelli³. We fit cubic-order polynomials to stars with $V - I < 1.5$ and obtained transformations with $rms < 0.01$ mag. Using the previously-discussed distance modulus for the LMC, this procedure yielded the following P-L relations in the SDSS *gri* filters:

$$g = -3.657(50) - 2.560(34)(\log P - 1) \quad \sigma = 0.261 \quad (1)$$

$$r = -4.148(49) - 2.845(23)(\log P - 1) \quad \sigma = 0.177 \quad (2)$$

$$i = -4.275(48) - 2.952(19)(\log P - 1) \quad \sigma = 0.148 \quad (3)$$

where the zeropoint uncertainties include the term associated with the distance modulus. We then calculated an independent set of P-L relations based on the theoretical Cepheid magnitudes in SDSS filters computed by Di Criscienzo et al. (2013). We restricted the dataset to $2.5 < P < 40$ d due to the incomplete filling of the instability strip beyond the upper period limit, which arises as a consequence of the upper mass limit considered in the models. We obtained:

$$g = -3.738(07) - 2.615(18)(\log P - 1) \quad \sigma = 0.214 \quad (4)$$

$$r = -4.241(05) - 2.882(13)(\log P - 1) \quad \sigma = 0.161 \quad (5)$$

$$i = -4.402(04) - 2.987(12)(\log P - 1) \quad \sigma = 0.139 \quad (6)$$

which are in excellent agreement in terms of the slopes with the previous set of relations; both sets are shown in Figure 2. We used each set of PLs to derive relations between the residuals of a given Cepheid in two bands, which we will use in our candidate selection process below. We found:

$$\Delta r = 0.752 \Delta g \quad \sigma = 0.028 \quad (7)$$

$$\Delta i = 0.650 \Delta g \quad \sigma = 0.038 \quad (8)$$

$$\Delta i = 0.864 \Delta r \quad \sigma = 0.015, \quad (9)$$

where the dispersions were calculated using the LMC data. We also calculated the 1σ -equivalent ranges spanned by the variables along the color-color relations, which were 0.27, 0.25 and 0.21 mag, respectively.

5. IDENTIFICATION OF CEPHEID VARIABLES

We used the TRIAL program (kindly provided by P. Stetson) to identify variable objects by calculating

³ <http://wwwuser.oats.inaf.it/castelli/colors.html>

TABLE 5
CEPHEID SELECTION STEPS

Step	Number
$L_r \geq 0.75$	4419
$N_r, N_i > 75\%$	4143
$A_i \geq 0.1$ mag	2530
non-aliased P	959
“ABC” grades	408
pass visual insp.	309

the modified Welch-Stetson variability index L (Stetson 1996) in the r -band data, setting $L_r = 0.75$ as the variability threshold and only considering objects with valid photometry in $\geq 75\%$ of the r & i images. There were 4143 objects that met these criteria; of these, 54% also had valid g photometry. We only expected a small fraction of the variables to be Cepheids, with the majority likely being irregular or semi-periodic RGB/AGB pulsators. We selected Cepheid candidates following the steps outlined below; the number of objects rejected at each stage are summarized in Table 5.

- We ran the Cepheid template-fitting program developed by Yoachim et al. (2009) on the $(g)ri$ light curves, using 100 initial trial periods spanning 7 to 124 days (spaced every 0.0125 dex in $\log P$). The lower limit was set by our sparse observational sampling and estimated completeness limit (described in §3.3) while the upper limit was set to search for ultra-long period Cepheids. We selected the best-fit period corresponding to the lowest value of χ^2 returned by the template-fitting program. We derived flux-weighted mean magnitudes by numerical integration of the best-fit template light curves, and calculated the light curve semi-amplitudes as half of the difference between the faintest and brightest points in the template. The uncertainties in both of these parameters were estimated by evaluating χ^2 over a grid of values while keeping the period fixed to the best-fit value.
- We discarded objects with i -band semi-amplitudes below 0.1 mag to remove blended objects and low-amplitude semi-regular variables. We generated histograms of the best-fit periods for the remaining variables to identify any possible aliasing due to the sparse nature of our observations. Using a bin size of $\Delta \log P = 10^{-3}$, we found that $\sim 70\%$ of the bins were empty and $\sim 25\%$ of the bins had only one variable. We flagged any bin with more than 4 variables as a possibly aliased period and reran the previous step excluding those periods from consideration. We identified any remaining aliased periods after the second iteration and removed those objects from further consideration.
- We carried out the template-fitting procedure described in (a) on the BVI and VI light curves of all fundamental-mode LMC Cepheids from OGLE-II (Udalski et al. 1999) and OGLE-III (Soszynski et al. 2008; Ulaczyk et al. 2013), respectively, except that we kept the periods fixed to the published values. We transformed the resulting best-fit templates into the gri system using the

previously-mentioned models by Castelli & Kurucz (2003) and calculated the light curve amplitude ratios exhibited by Cepheids in these bands. We found $A_g/A_r = 1.610 \pm 0.062$ and $A_i/A_r = 0.781 \pm 0.024$. We then classified the remaining variables in NGC 4258 according to their amplitude ratios; objects within 6σ of the LMC values were given a grade of “A”, those at $6-9\sigma$ “B”, those at $9-12\sigma$ “C”, and the rest “F”. Variables without valid g photometry were classified solely based on their i -to- r amplitude ratio. Figure 3 shows the result of this step.

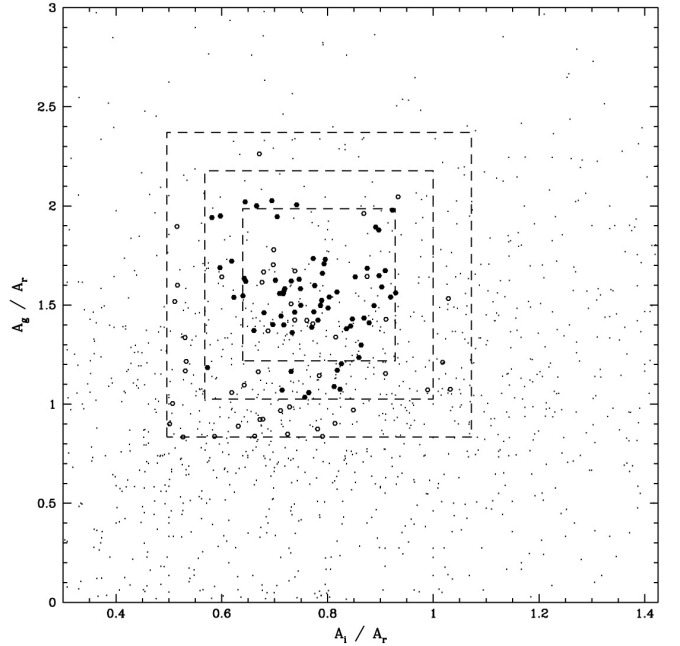


FIG. 3.— Amplitude ratios derived from the best-fit Cepheid template light curves for all variables with $L_r \geq 0.75$. Dashed lines indicate the various regions used to grade variables (A, B, C or F) based on the amplitude ratios spanned by LMC Cepheids. Filled symbols denote objects listed in Table 6; open symbols represent objects listed in Table 7, and small dots represent variables rejected at any step of the selection process.

- We selected variables with a grade of “A” from the preceding step, gri photometry and $15 < P < 100d$ as our reference subsets (to avoid incompleteness bias at the short end and possible non-linearities at the long end) and fit the P-L relations listed in Equations 4–6. We calculated the residuals of all variables in all bands relative to the best-fit relations and fit them using the relations listed in Equations 7–9. We flagged (with a grade of “C”) and removed from further fitting any object with a residual in any band exceeding 1 mag in absolute value, as these are likely either badly blended Cepheids (on the bright side) or heavily reddened Cepheids/Pop II variables (on the faint side). We flagged (with a grade of “B”) and removed from further fitting any objects lying beyond 6σ of the dispersions determined in Equations 7–9 and with residuals greater than 2.5σ based

on the observed dispersion for NGC 4258 Cepheids. We only flagged and removed one object per band on each iteration and continued until convergence. Figure 4 shows the result of this step.

- e. Finally, we inspected the master images at the location of each variable to ensure that all candidates were well-resolved and isolated point sources, located at least $0''.5$ away from chip edges.

The final Cepheid sample contains 94 objects (listed in Table 6) that received a grade of “A” or “B” in steps (c) and (d). Variables with a grade of “C” in either step are listed in Table 7; these 215 objects are probably blends, highly reddened Cepheids, or Population II pulsators. The locations of both sets of objects within the Gemini fields are shown in Figures 5a & 5b, while individual finding charts can be found in Figures 6a-6g. Representative light curves are plotted in Figure 7 and all light curve data is presented in Table 8.

6. RESULTS

We calculated the Cepheid detection efficiency and robustness of the derived periods by comparing our sample with that of Macri et al. (2006) over the areas in common (see Figure 1). There are 246 Cepheids from that study with $4 < P < 45$ d located within our fields. As expected from the artificial star tests described in §3.3, our ability to detect significant variability ($L_r \geq 0.75$) was very low (9%) for $P < 7$ d Cepheids, increasing to 42% and 56% for $7 < P < 15$ d and $P > 15$ d, respectively. Focusing on the last group, 53% of the detected variables were ultimately rejected because of aliased periods or very low pulsation amplitudes (rejection criterion “b” in §5), 41% were classified as Cepheids, and 6% classified as “variables” (highly reddened/blended Cepheids or Pop. II pulsators). The periods we derived for the objects classified as Cepheids were very robust, with $\langle \Delta \log P \rangle = -0.005 \pm 0.010$ relative to their HST-based values. We also compared our results with those of Fausnaugh et al. (2014). We detected significant variability for 79% of their Cepheids located within our fields and classified 74% of these as Cepheids, 4% as lower-quality variables, and rejected the remaining 22%. A comparison of the periods for Cepheids in common again revealed excellent agreement for all but one object, with $\langle \Delta \log P \rangle = -0.0007 \pm 0.0001$. After taking into account objects present in the two aforementioned studies, our survey contributes an additional 57 Cepheids & 205 variables.

We present the P-L relations for Cepheids and variables in our sample in Figure 8. The Cepheid relations become incomplete at $P \sim 15$ d, as expected from the artificial star tests and the detection efficiency discussed above. We fit the P-L relations listed in Eqns. 4-6 to the 40 Cepheids in Table 6 with *gri* data and $15 < P < 100$ d and obtained apparent distance moduli of $\mu_g = 29.29 \pm 0.06(r) \pm 0.04(s)$, $\mu_r = 29.24 \pm 0.05(r) \pm 0.04(s)$ and $\mu_i = 29.24 \pm 0.05(r) \pm 0.05(s)$ mag (where *r* and *s* are used to denote random and systematic uncertainties, respectively). We adopted the extinction law of Fitzpatrick (1999) with $R_V = 3.1$ and solved for the best-fit values of true distance modulus and reddening. Given the rather large uncertainties in the individual distance moduli and

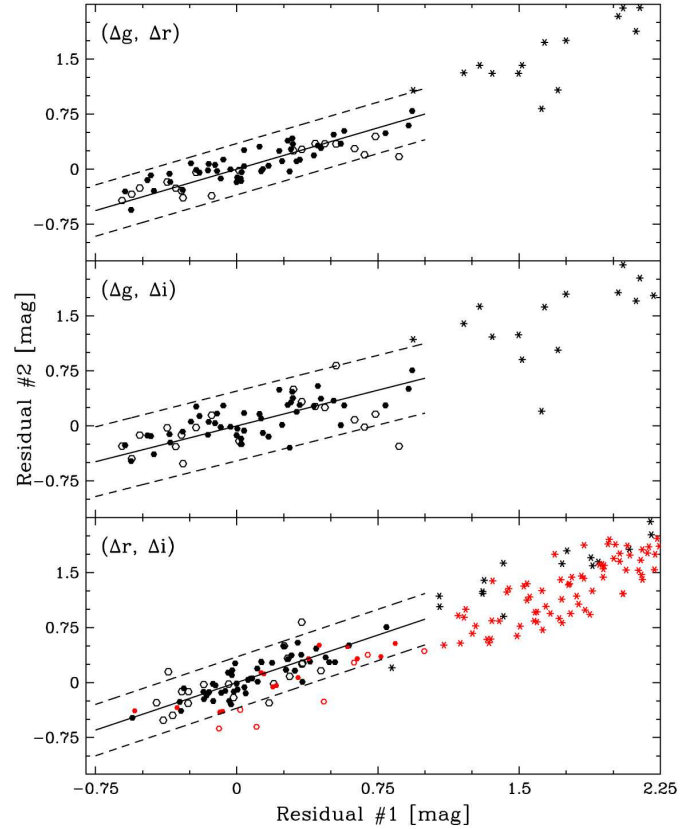


FIG. 4.— Correlation of P-L residuals for all objects listed in Tables 6 & 7, relative to the best-fit P-L relations for objects with “A”-grade amplitude ratios and $15 < P < 100$ d. Filled symbols denote Cepheids with “A” grade in amplitude ratios and PL residuals while open symbols denote Cepheids with “B” grade in at least one category. Starred symbols represent objects listed in Table 7. Red symbols are used for object with only *r* and *i* photometry.

the short wavelength baseline provided by the filters we used, there is a large covariance between these two parameters. Nevertheless, we find $\mu_0 = 29.18 \pm 0.23$ mag and $E(B-V) = 0.03 \pm 0.08$ mag, which are consistent at the 1σ level with the maser-based distance modulus of $\mu_0 = 29.404 \pm 0.065$ mag (Humphreys et al. 2013) and the foreground Galactic reddening towards NGC 4258 of $E(B-V) = 0.014$ mag (Schlafly & Finkbeiner 2011). Given the very shallow abundance gradient in NGC 4258 (Bresolin 2011), the Cepheids in our sample lie in areas of the disk that span a narrow range of LMC-like metallicities ($\langle [O/H] \rangle = 8.34 \pm 0.07$ dex). We are therefore unable to provide any constraints on the “metallicity effect” at these wavelengths (for a recent study of this issue, see Fausnaugh et al. 2014).

Figure 8 also shows the expected P-L relations for Population II Cepheids in *r* and *i*, which match fairly well the distribution of periods and magnitudes of the variables listed in Table 7. The slopes of those relations were fixed to the values derived by Kodric et al. (2013, Table 3, entries labeled “PLC”, which stands for clipped P-L relation) and the zeropoints were obtained by shifting the best-fit mean magnitudes of our observed P-L relations for “classical” (i.e., Population I) Cepheids at $P = 80$ d by +1.91 mag. This average offset was derived by calculat-

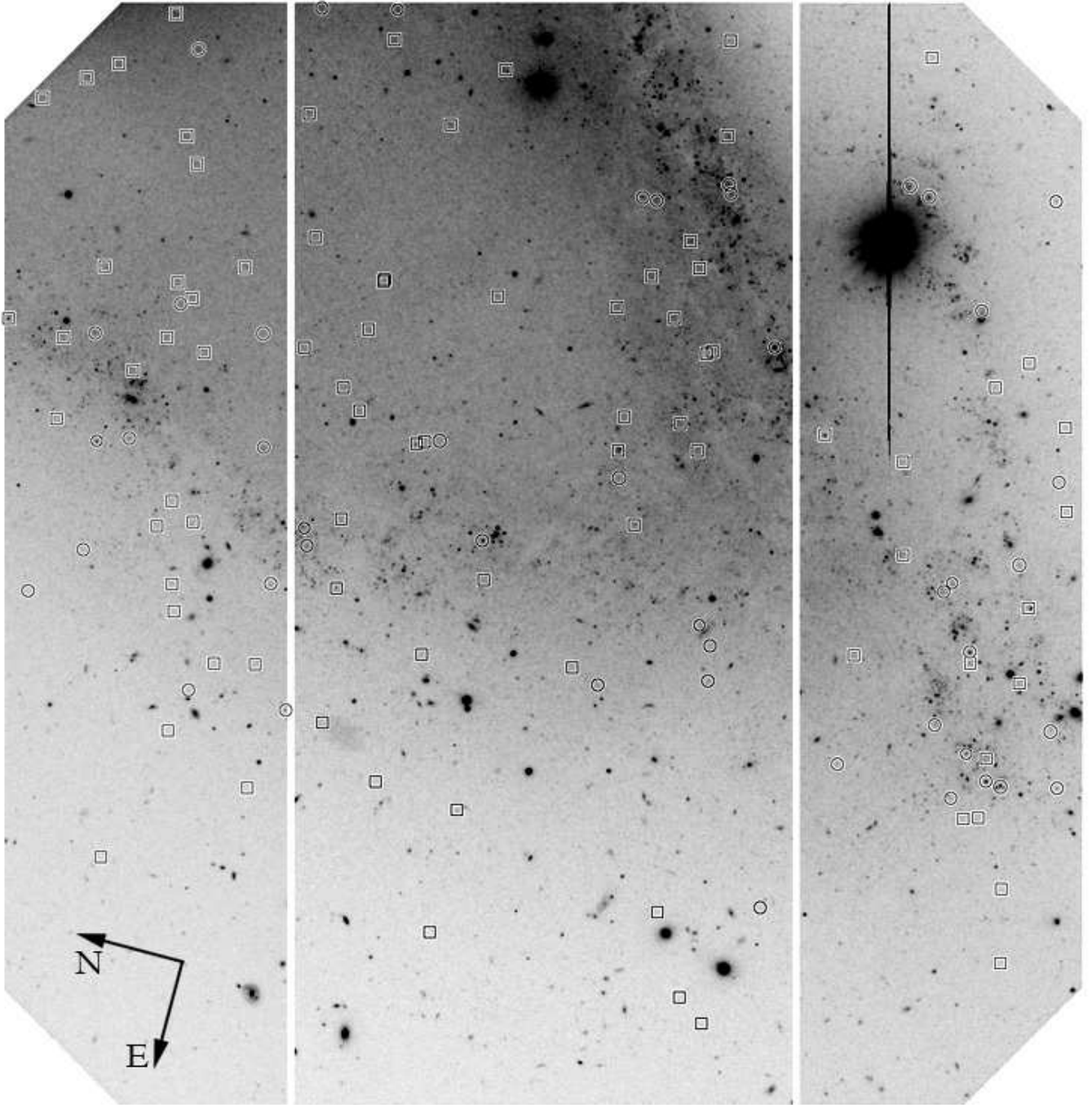


FIG. 5A.— r -band image of the Gemini outer field in NGC 4258. The locations of Cepheids (listed in Table 6) and variables (listed in Table 7) are indicated by circles and squares, respectively. The image is $5''.5$ on a side.

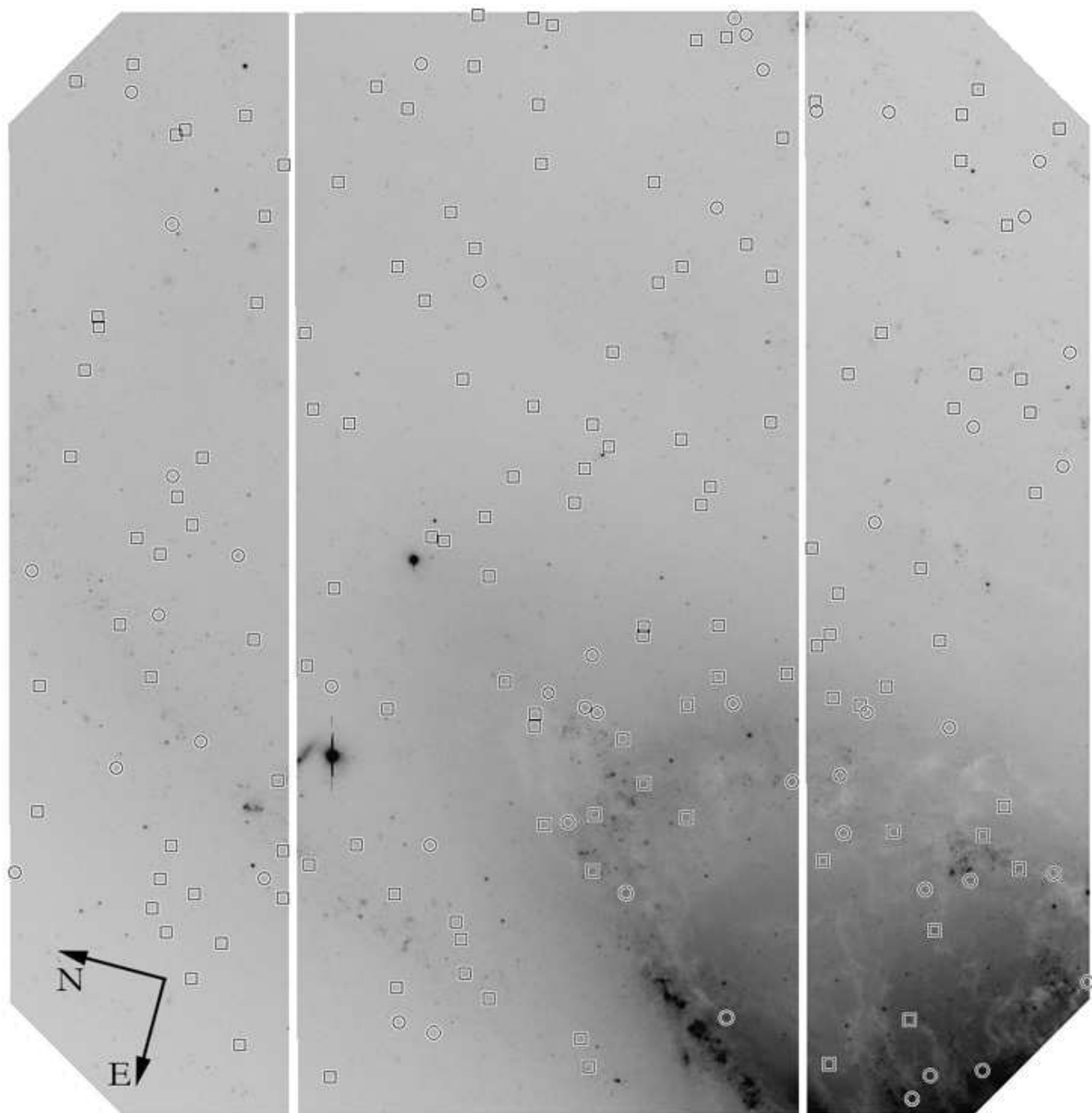


FIG. 5B.— Same as 5a, but for the Gemini inner field in NGC 4258.

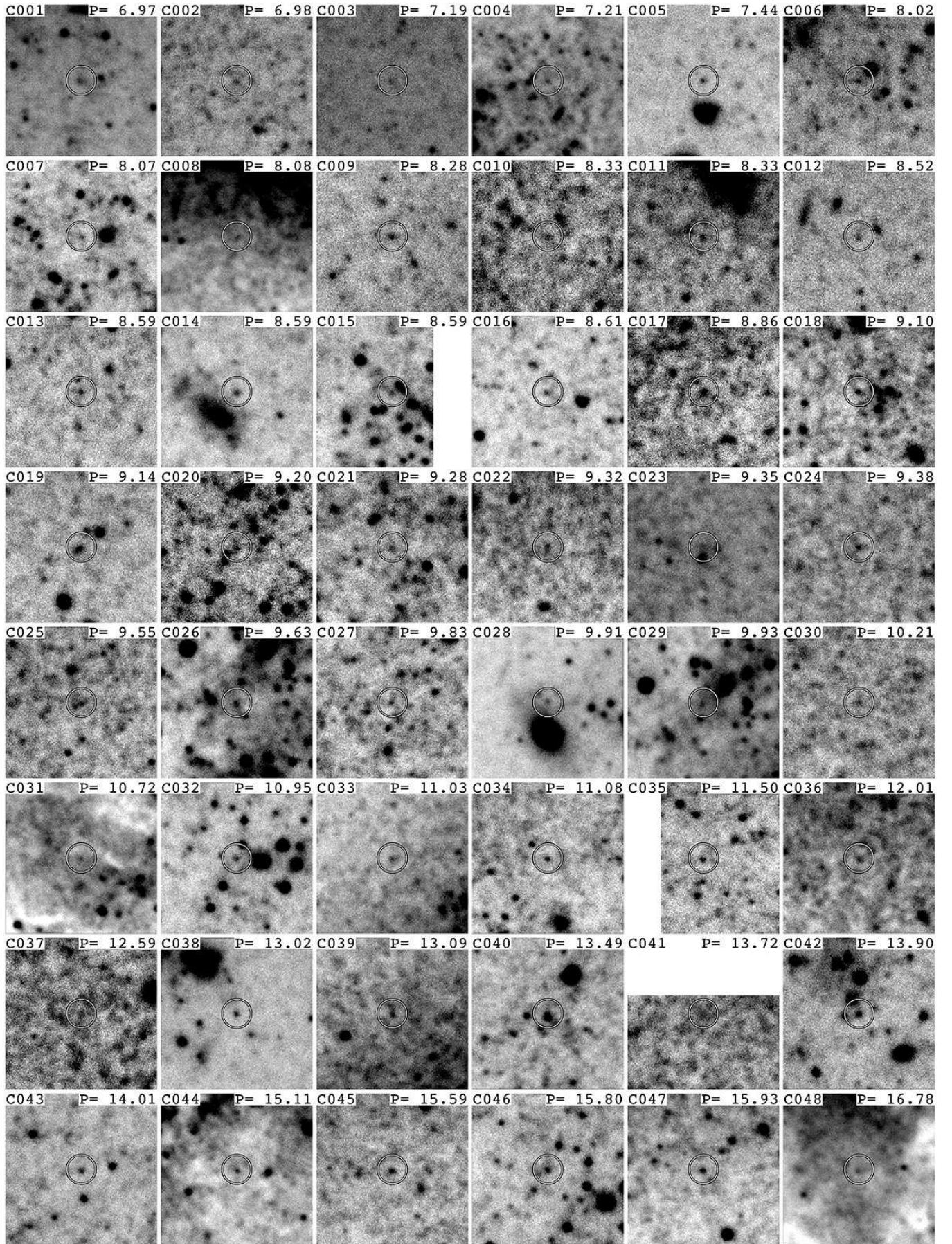


FIG. 6A.— Individual finding charts for the Cepheids and variables discovered in this work, listed in Tables 6 and 7. Each panel is $14''/2$ on a side.

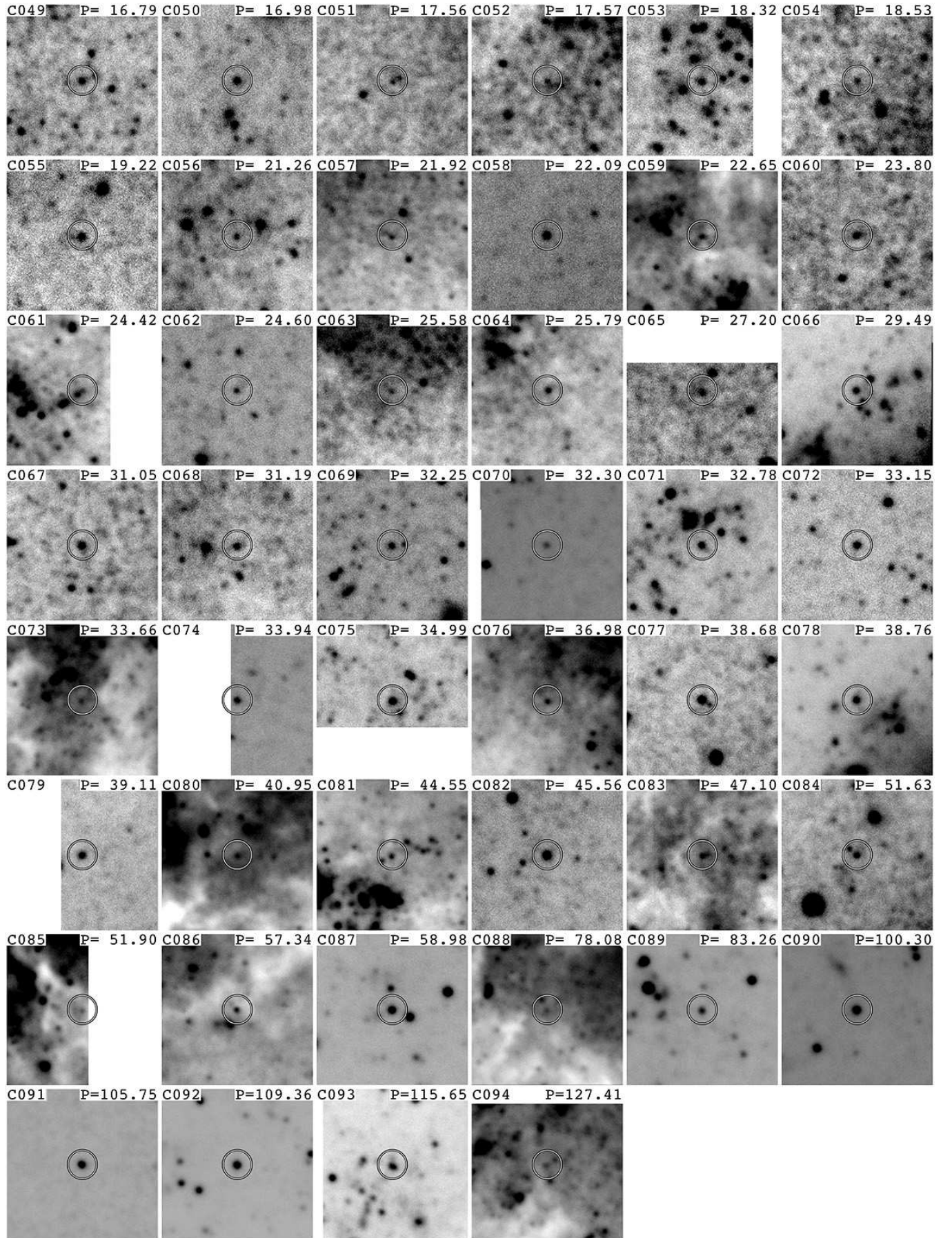


FIG. 6B.— continued.

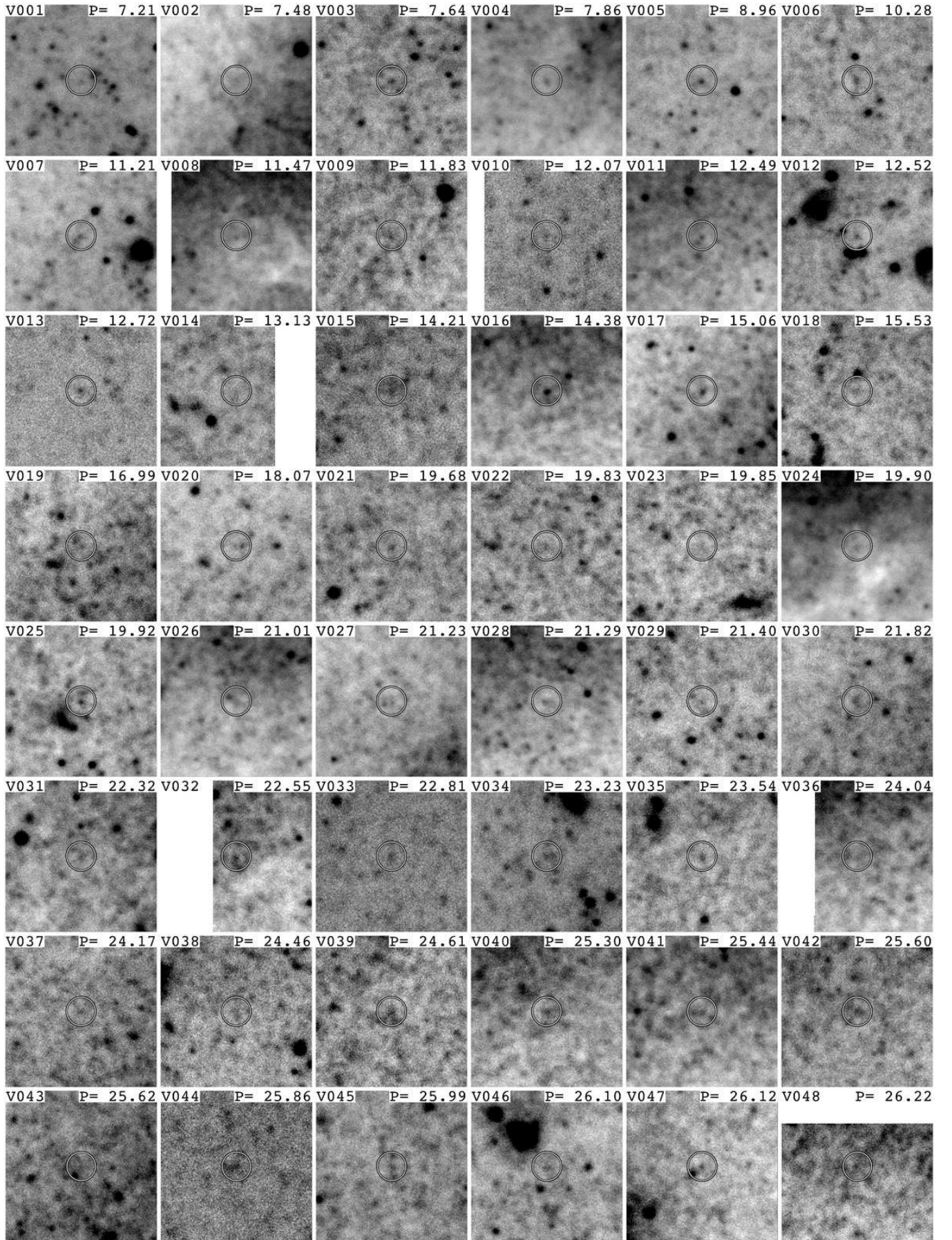


FIG. 6c.— continued.

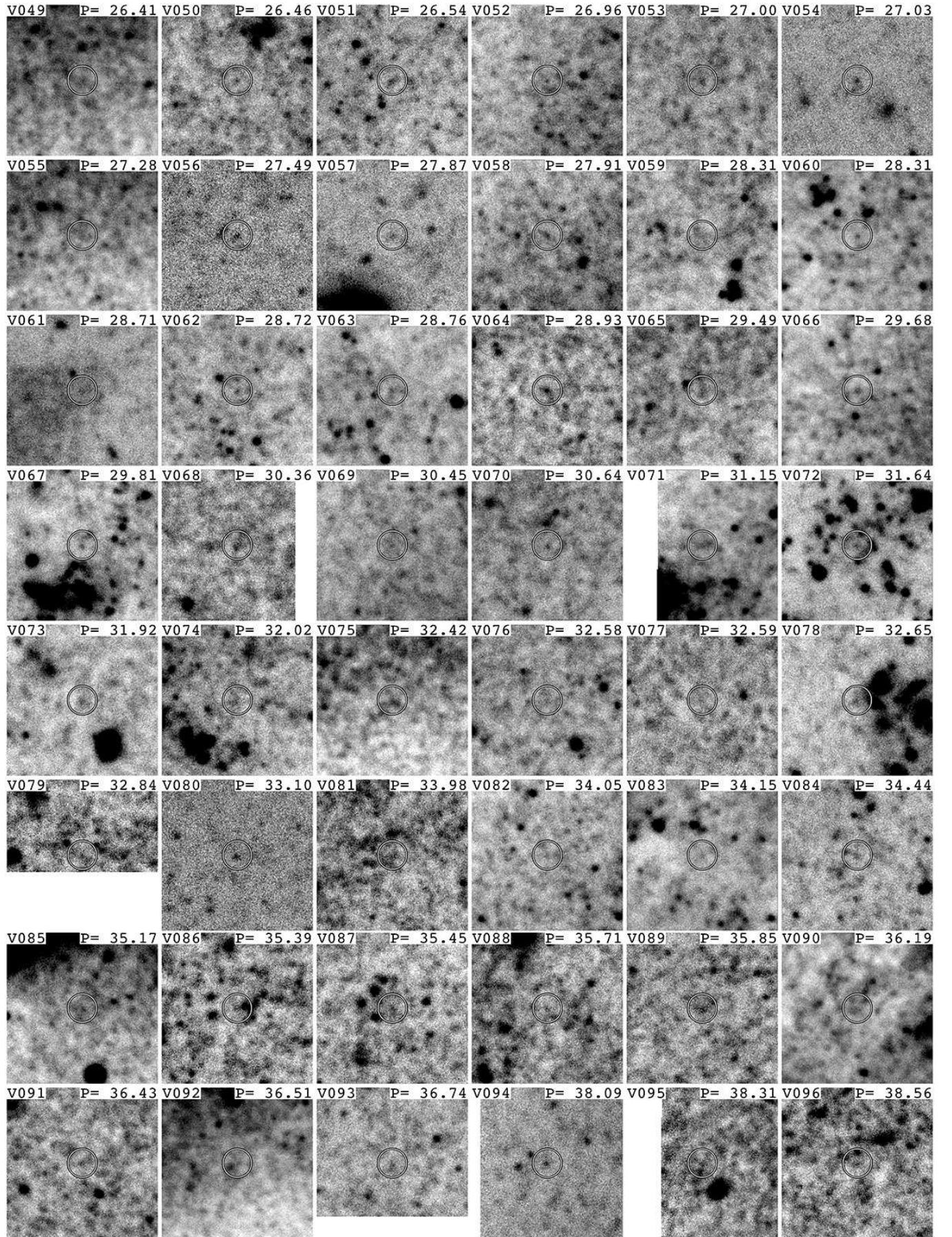


FIG. 6D.— continued.

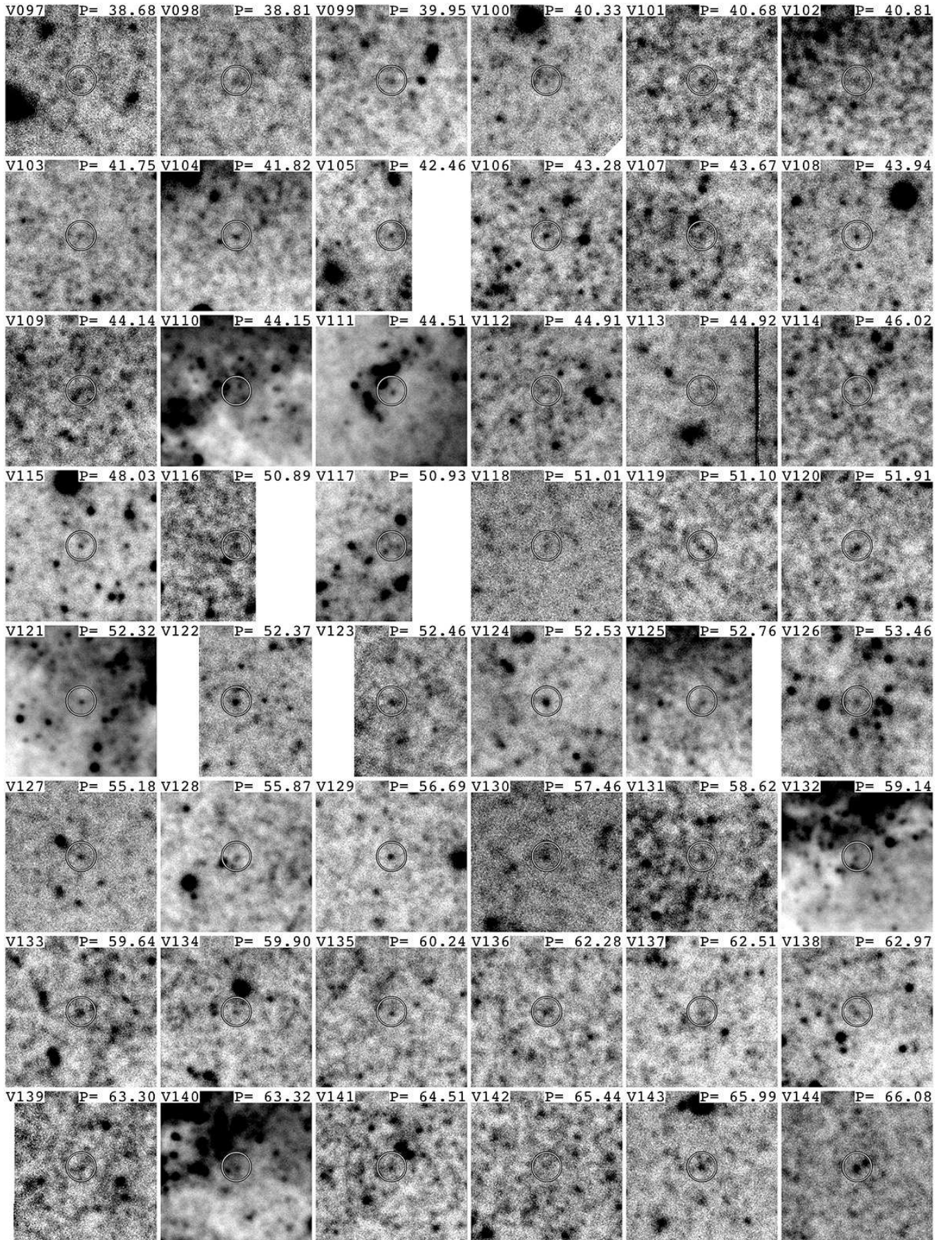


FIG. 6E.— continued.

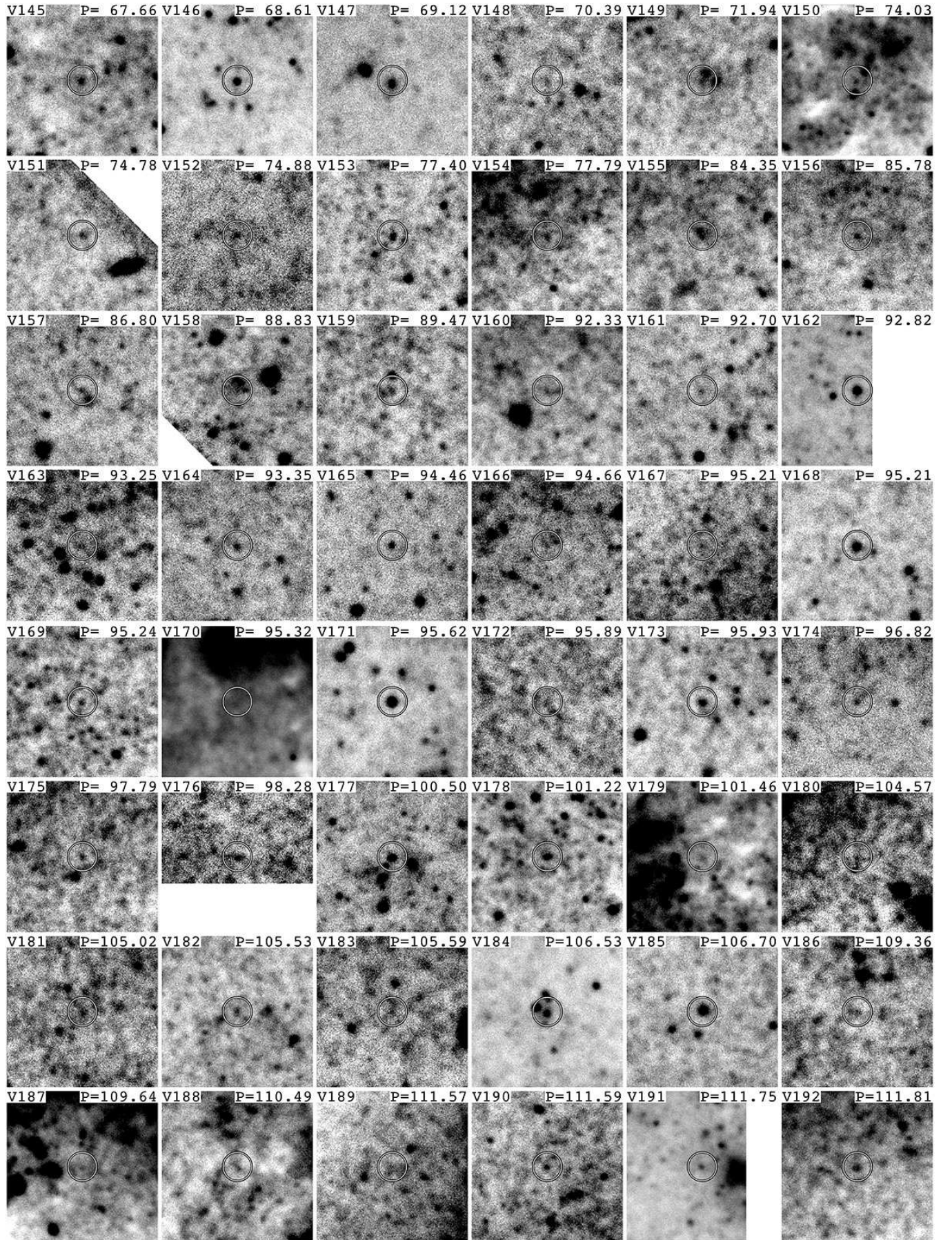


FIG. 6F.— continued.

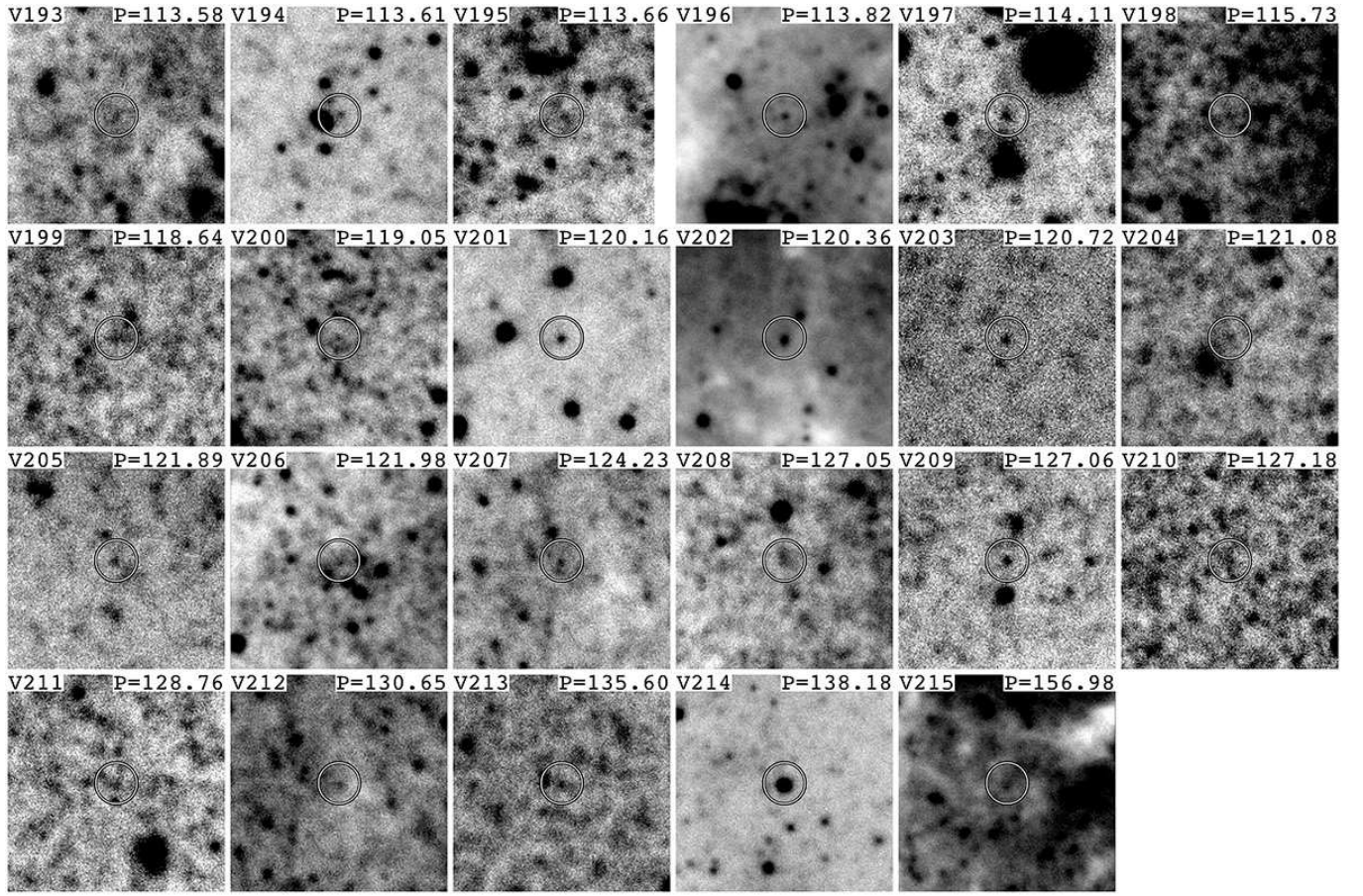


FIG. 6G.— continued.

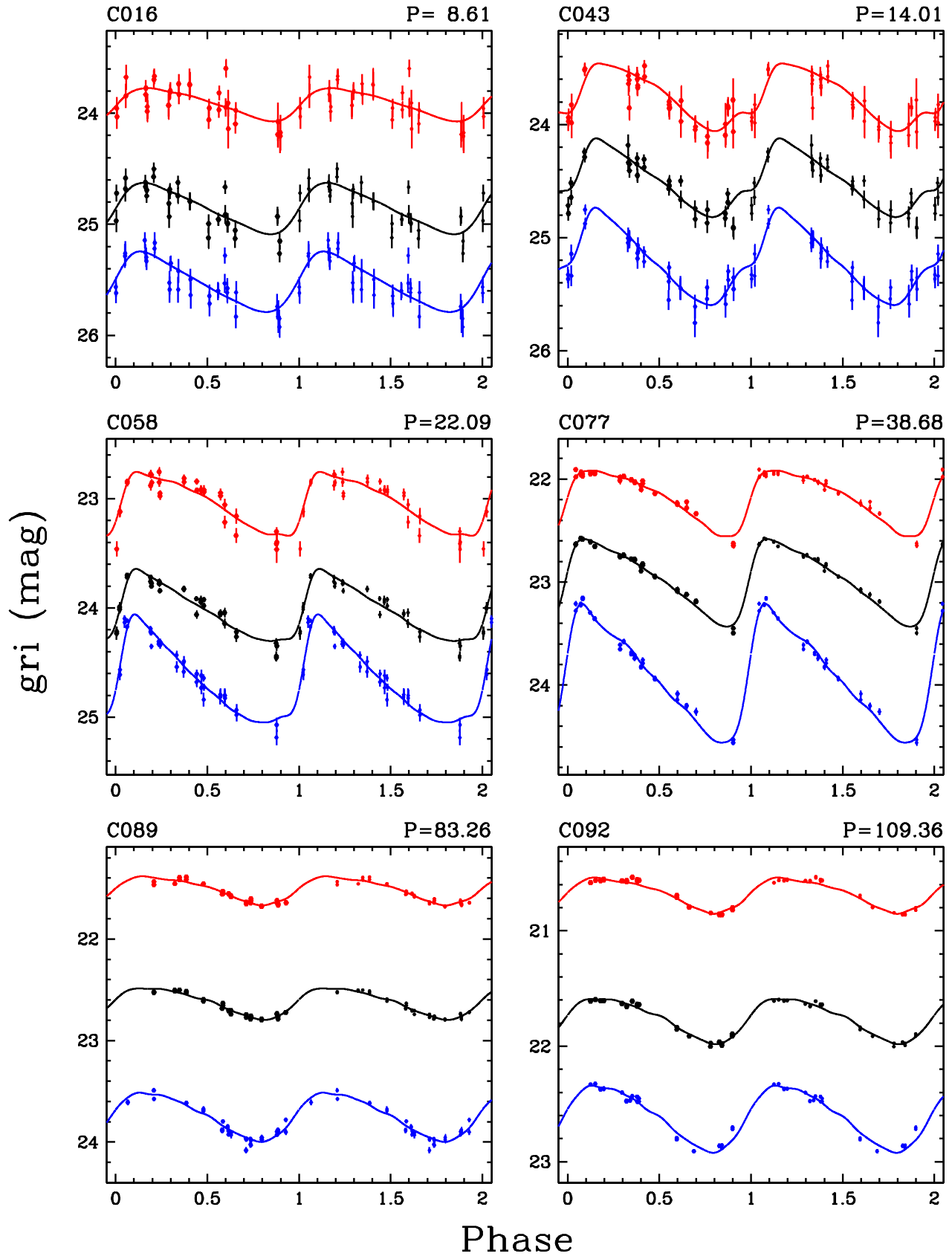


FIG. 7.— Representative Cepheid light curves. Filled symbols represent the Gemini photometry while the solid lines are the best-fit templates from Yoachim et al. (2009). Offsets were added to the gi magnitudes and templates for clarity.

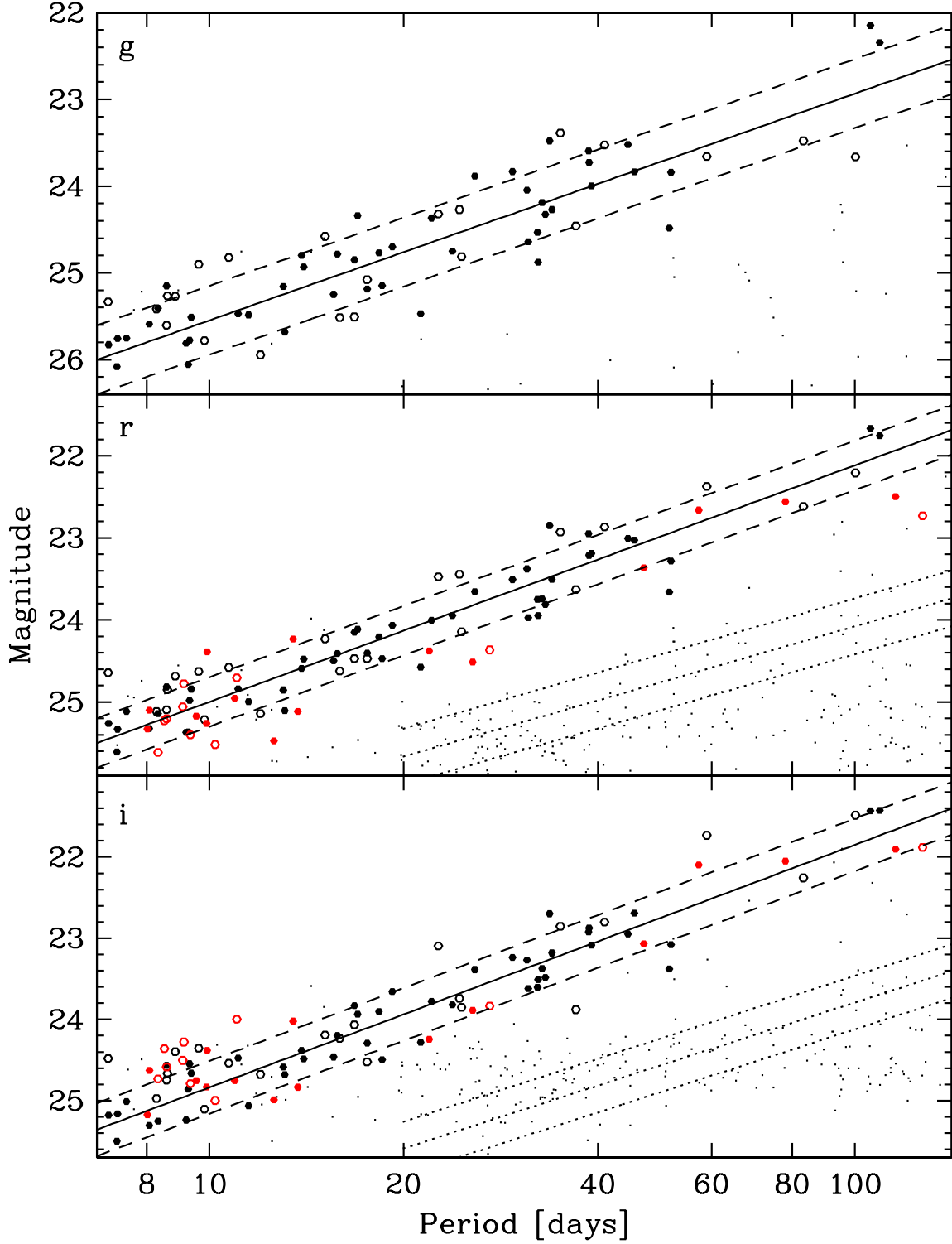


FIG. 8.— Period-Luminosity relations in *gri* (top to bottom) for Cepheids and other variables in NGC 4258. Filled symbols denote Cepheids with “A” grade in amplitude ratios and PL residuals while open symbols denote Cepheids with “B” grade in at least one category. Red symbols are used for Cepheids with only *r* and *i* photometry. Small dots represent objects listed in Table 7. The uncertainties in mean magnitude and period are comparable to the size of the symbols. The slopes of the Cepheid P-L relations (solid lines) were fixed to the values derived from the theoretical Cepheid magnitudes of Di Criscienzo et al. (2013) as described in §4; the dashed lines indicate the $\pm 2\sigma$ dispersion of the fits. The dotted lines in the *r* and *i* panels represent the Pop II P-L relations of Kodric et al. (2013) shifted to the distance modulus of NGC 4258 as described in §6.

TABLE 6
 NGC 4258 CEPHEIDS

ID	RA (J2000) [deg]	Dec	P [d]	Mean magnitudes						Lightcurve ampl.			Qual. flag		Cross ID
				r	i	g	σ_r	σ_i	σ_g	r	i	g	A	R	
C001	184.84502	47.24399	6.975	24.642	24.481	25.335	10	14	13	185	106	219	B	B	
C002	184.62722	47.33035	6.980	25.259	25.181	25.828	17	25	26	229	181	380	A	A	
C003	184.86600	47.24885	7.192	25.607	25.501	26.079	22	40	26	214	175	335	A	A	
C004	184.71477	47.38594	7.212	25.330	25.164	25.755	23	28	31	332	245	486	A	A	
C005	184.87254	47.23393	7.441	25.115	25.009	25.752	13	23	19	237	202	389	A	A	
C006	184.86076	47.16932	8.022	25.326	25.176	...	17	27	...	295	234	...	A	A	
C007	184.61502	47.35720	8.075	25.321	25.307	25.589	22	35	28	344	222	557	A	A	
C008	184.69374	47.34410	8.076	25.100	24.628	...	22	20	...	196	141	...	A	A	MI118600
C009	184.82037	47.16744	8.285	25.114	24.975	25.415	14	22	20	190	132	385	B	A	
C010	184.83517	47.21822	8.327	25.614	24.731	...	26	21	...	334	217	...	A	B	
C011	184.85062	47.19240	8.333	25.142	25.252	25.409	17	33	22	230	183	398	A	A	MO011990
C012	184.87982	47.18283	8.520	25.227	24.358	...	19	14	...	274	221	...	A	B	
C013	184.86028	47.17903	8.588	25.095	24.745	25.603	14	18	26	194	125	392	B	A	MO005306
C014	184.84859	47.19366	8.588	24.816	24.564	25.150	12	16	16	248	191	344	A	A	
C015	184.84962	47.22719	8.592	25.202	24.586	...	19	17	...	271	162	...	B	B	
C016	184.64165	47.32391	8.610	24.851	24.665	25.263	12	17	16	259	198	274	B	A	
C017	184.62840	47.38239	8.861	24.683	24.396	25.269	11	14	17	244	151	420	B	A	
C018	184.70121	47.39193	9.102	25.058	24.504	...	16	14	...	242	179	...	A	B	
C019	184.85887	47.20052	9.135	24.777	24.278	...	12	14	...	208	129	...	B	B	MO009786
C020	184.61926	47.34332	9.205	25.368	25.239	25.809	19	29	27	239	192	368	A	A	
C021	184.83388	47.20322	9.282	25.364	24.860	26.055	21	23	56	272	244	511	A	A	MO025226
C022	184.79720	47.24684	9.319	24.980	24.547	25.778	14	15	23	166	117	323	A	A	
C023	184.84171	47.23315	9.353	25.402	24.791	...	18	19	...	171	163	...	B	B	
C024	184.82768	47.24281	9.376	24.842	24.662	25.513	12	17	17	373	316	533	A	A	
C025	184.63615	47.35587	9.546	25.172	24.755	...	17	19	...	216	154	...	A	A	
C026	184.79710	47.20031	9.633	24.628	24.355	24.902	12	16	14	279	204	325	B	A	
C027	184.64081	47.40509	9.833	25.214	25.105	25.782	21	27	33	366	228	563	B	A	
C028	184.80280	47.17722	9.907	25.259	24.834	...	19	24	...	188	173	...	A	A	
C029	184.79607	47.20068	9.929	24.388	24.379	...	11	16	...	148	135	...	A	A	
C030	184.82851	47.23561	10.210	25.518	24.998	...	21	22	...	321	306	...	B	A	
C031	184.70499	47.33163	10.724	24.578	24.537	24.823	13	19	16	278	229	299	B	A	MI091209
C032	184.83676	47.17423	10.950	24.952	24.753	...	12	17	...	264	204	...	A	A	MO014709
C033	184.74165	47.36098	11.033	24.704	23.999	...	12	09	...	255	170	...	A	B	
C034	184.65521	47.32207	11.082	24.841	24.474	25.469	12	12	19	191	136	276	A	A	
C035	184.62136	47.34912	11.503	24.996	25.064	25.484	13	25	20	335	308	516	A	A	
C036	184.69243	47.35635	12.006	25.140	24.677	25.946	24	24	55	285	170	481	B	A	MI126353
C037	184.65205	47.37317	12.589	25.475	24.988	...	27	27	...	386	263	...	A	A	
C038	184.84975	47.16279	13.020	24.853	24.586	25.156	12	15	16	359	324	571	A	A	
C039	184.74147	47.36389	13.091	25.106	24.682	25.682	20	19	30	307	240	437	A	A	
C040	184.65503	47.39910	13.490	24.230	24.022	...	08	09	...	265	180	...	A	A	
C041	184.78815	47.23692	13.715	25.114	24.835	...	17	23	...	290	242	...	A	A	
C042	184.85266	47.17209	13.896	24.592	24.384	24.800	10	15	12	293	263	483	A	A	
C043	184.61859	47.35511	14.008	24.476	24.484	24.929	10	15	12	348	299	430	A	A	
C044	184.69910	47.35472	15.112	24.230	24.191	24.579	09	13	12	416	338	453	B	A	MI117710
C045	184.65344	47.32998	15.585	24.496	24.462	25.248	09	14	17	351	263	526	A	A	MI144134
C046	184.83560	47.17372	15.801	24.409	24.196	24.783	07	11	12	296	259	499	A	A	MO015276
C047	184.66770	47.33579	15.931	24.620	24.234	25.514	13	14	30	472	282	920	B	A	MI138294
C048	184.70912	47.32398	16.778	24.471	24.066	25.508	15	13	50	387	287	776	B	A	MI075254
C049	184.83369	47.24899	16.790	24.148	23.830	24.850	06	08	09	301	233	441	A	A	
C050	184.83134	47.16879	16.975	24.112	23.935	24.342	05	08	08	345	228	473	A	A	F56
C051	184.70419	47.37639	17.560	24.469	24.522	25.079	11	17	15	423	302	453	B	A	
C052	184.69827	47.35901	17.567	24.404	24.292	25.187	10	14	20	389	271	545	A	A	MI121312
C053	184.85165	47.22660	18.317	24.205	23.904	24.769	07	09	12	453	325	711	A	A	
C054	184.71974	47.36516	18.533	24.473	24.497	25.147	12	18	19	443	385	635	A	A	
C055	184.85487	47.19178	19.219	24.065	23.655	24.701	06	07	11	333	214	544	A	A	
C056	184.80025	47.20615	21.265	24.573	24.280	25.473	12	15	34	450	401	852	A	A	
C057	184.69022	47.33243	21.919	24.377	24.244	...	12	13	...	398	332	...	A	A	MI116159
C058	184.78761	47.17361	22.093	24.002	23.780	24.368	05	07	09	330	293	494	A	A	F48
C059	184.69841	47.33317	22.651	23.475	23.096	24.322	06	06	11	356	207	691	B	B	MI104131,F40
C060	184.68451	47.39373	23.803	23.945	23.819	24.750	05	07	11	397	315	678	A	A	
C061	184.70107	47.33777	24.417	23.441	23.742	24.270	10	16	18	330	300	552	A	B	MI103070
C062	184.85942	47.24532	24.599	24.145	23.851	24.812	09	10	23	434	289	868	B	A	F35
C063	184.68946	47.32550	25.585	24.512	23.889	...	11	08	...	403	274	...	A	A	
C064	184.69884	47.35583	25.790	23.654	23.386	23.885	06	07	06	323	298	639	A	A	MI118782,F14
C065	184.78604	47.23080	27.196	24.365	23.834	...	17	18	...	330	316	...	B	A	
C066	184.79041	47.18555	29.487	23.507	23.236	23.832	05	07	07	432	316	700	A	A	
C067	184.70006	47.40289	31.053	23.377	23.266	24.045	03	05	06	402	300	655	A	A	F22
C068	184.80029	47.20732	31.192	23.970	23.621	24.640	06	07	11	436	343	653	A	A	F07
C069	184.62033	47.33033	32.250	23.747	23.606	24.534	05	06	09	455	359	693	A	A	F44
C070	184.85760	47.22968	32.302	23.945	23.511	24.875	05	06	08	378	257	552	A	A	F04
C071	184.85500	47.16898	32.784	23.744	23.375	24.190	05	06	07	438	315	693	A	A	MO005713
C072	184.85625	47.16104	33.148	23.811	23.484	24.327	03	05	07	307	259	428	A	A	F51
C073	184.73065	47.31969	33.662	22.848	22.698	23.478	05	06	08	305	268	430	A	A	MI008723
C074	184.87186	47.22579	33.943	23.503	23.181	24.270	03	04	06	455	353	727	A	A	F17
C075	184.61339	47.35845	34.991	22.928	22.853	23.386	02	03	03	369	302	432	B	A	
C076	184.71275	47.35470	36.981	23.630	23.879	24.460	06	12	13	457	382	631	A	B	MI095995,F31
C077	184.72058	47.39204	38.684	22.947	22.920	23.594	02	03	04	426	319	674	A	A	F09
C078	184.79111	47.18379	38.760	23.211	22.873	23.725	02	02	06	469	329	762	A	A	

NOTE. — Table continues in next page.

TABLE 6
NGC 4258 CEPHEIDS – *continued*

ID	RA (J2000) [deg]	Dec	P [d]	r	Mean magnitudes					Lightcurve ampl.			Qual. flag		Cross ID
					i [mag]	g	σ_r	σ_i [mmag]	σ_g	r	i [mmag]	g	A	R	
C079	184.73595	47.39787	39.108	23.189	23.085	23.998	02	03	05	392	303	680	A	A	F23
C080	184.73083	47.33796	40.951	22.865	22.802	23.523	05	06	07	374	309	450	B	A	MI032759
C081	184.70659	47.32061	44.551	23.005	22.950	23.522	03	04	06	352	304	457	A	A	MI077610
C082	184.84634	47.24652	45.562	23.027	22.690	23.834	02	03	03	296	212	461	A	A	F18
C083	184.71928	47.34868	47.104	23.363	23.068	...	06	06	...	300	255	...	A	A	F64
C084	184.72884	47.37802	51.629	23.662	23.380	24.485	04	06	07	214	137	331	A	A	F24
C085	184.71481	47.30915	51.896	23.282	23.081	23.842	07	07	08	258	183	402	A	A	
C086	184.70316	47.31416	57.338	22.661	22.096	...	03	02	...	270	218	...	A	A	
C087	184.85777	47.16559	58.984	22.372	21.732	23.656	02	02	04	144	109	149	B	B	
C088	184.72849	47.31558	78.078	22.560	22.048	...	06	07	...	179	116	...	A	A	
C089	184.84549	47.21271	83.258	22.616	22.257	23.478	02	02	03	155	144	242	B	A	
C090	184.84308	47.17088	100.297	22.208	21.485	23.661	01	01	04	145	104	203	A	B	
C091	184.69186	47.38691	105.750	21.667	21.429	22.146	01	01	01	236	173	321	A	A	
C092	184.85767	47.16682	109.365	21.753	21.424	22.347	01	01	02	196	157	291	A	A	
C093	184.81371	47.19359	115.654	22.497	21.902	...	02	02	...	172	129	...	A	A	
C094	184.73400	47.32057	127.408	22.732	21.881	...	05	02	...	145	113	...	A	B	

NOTE. — The uncertainties in mean magnitude reflect only the statistical component; please refer to Table 2 for systematic uncertainties. Quality flags: A, amplitude ratios; R, P-L residuals. Cross-IDs: F=Fausnaugh et al. (2014); M=Macri et al. (2006).

ing the magnitude difference between the Kodric et al. (2013) “PLC” relations for classical (“FM”) and Population II (“T2”) Cepheids in r and i for periods ranging from 30–100d, which exhibited a dispersion of only 0.02 mag. Color-magnitude diagrams of the Cepheids and other variables are plotted in Figure 9. The semi-empirical P-L relations of §4 were used to illustrate the approximate location and intrinsic width of the zero-extinction instability strip. There is some evidence for differential extinction among Cepheids with $P > 80$ d, which is commonly seen in other galaxies since these are the youngest Cepheids and therefore are closest to their natal regions. The variables listed in Table 7 are mostly located in the AGB/RGB region of the diagram, as expected given their likely nature (Population II pulsator or highly-reddened classical Cepheid).

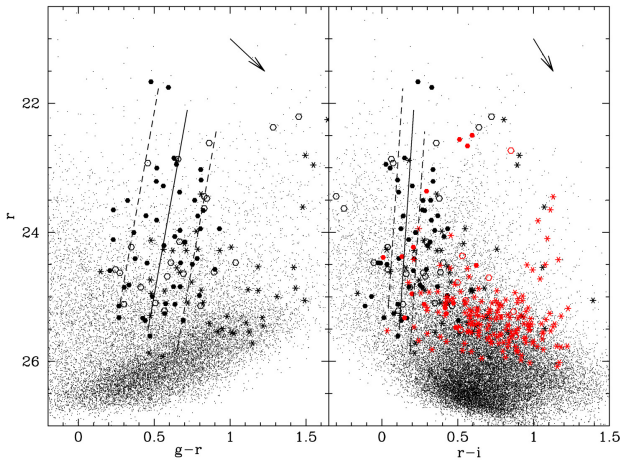


FIG. 9.— Color-magnitude diagrams of stars in NGC 4258, using $g-r$ (left) and $r-i$ (right). Symbols have the same meaning as Fig. 8, except that red starred symbols are used to plot objects listed in Table 7. The center of the zero-extinction instability strip is marked with a solid line, while the dotted lines represent its 2σ width. Extinction vectors for $A_v = 0.2$ mag are plotted.

7. PROSPECTS FOR LSST

Our results have demonstrated the feasibility of discovering Cepheids and other long-period variables with 8-m class telescopes out to significantly larger distances than before ($D \sim 4.5$ Mpc for M83, Thim et al. 2003). Furthermore, the work carried out by Gerke et al. (2011) and Fausnaugh et al. (2014) have highlighted the efficacy of difference imaging techniques for these surveys, as originally demonstrated by Bonanos & Stanek (2003).

The Large Synoptic Survey Telescope (LSST), slated to start operations by the end of the decade, will deliver images of most of the southern sky with angular resolution and depth (5σ limiting magnitude) comparable to the data collected as part of our survey (LSST average values: $0''.73$, $g \sim 24.9$, $r \sim 24.6$, $i \sim 24.0$; our survey: $< 0''.7$, $g \sim 26.5$, $r \sim 26.4$, $i \sim 25.8$), but with a vastly superior temporal sampling (LSST: ~ 32 epochs in g and ~ 73 in r & i ; our survey: ~ 16 per band). Based on the calculations described below, we expect that LSST will enable efficient searches for Cepheids and long-period variables in a considerable number of galaxies out to at least $D \sim 10$ Mpc. At this distance, the typical LSST single-image depth in r will be comparable to the mean magnitude of a $P \sim 25$ d classical Cepheid or a $P \sim 100$ d Pop II variable.

We used the Extragalactic Distance Database (EDD, Tully et al. 2009) and the Cosmicflows-2 catalog of distances (Tully et al. 2013) to identify spiral or dwarf galaxies that would be suitable for Cepheid searches with LSST based on the following criteria: (i) $D < 10$ Mpc; (ii) $-63^\circ < \delta < 0^\circ$ and $|b| \geq 10^\circ$ (the approximate boundaries of the “wide-fast-deep” survey mode); (iii) $i \leq 78^\circ$ for spirals (i.e., no more inclined than M31). There are 77 galaxies that meet this criteria, which are listed in Table 9. We include all dwarf galaxies regardless of their recent star formation history because Population II pulsators should be detectable (with a period limit $\sim 4\times$ larger than Population I Cepheids for a given apparent magnitude limit). We also included NGC 5128 despite its “early type” classification because it has been shown to host Population I Cepheids (Ferrarese et al. 2007) as well as a significant population of LPVs (Rejkuba 2004).

TABLE 7
 NGC 4258 VARIABLES

ID	RA (J2000) [deg]	Dec	P [d]	Mean magnitudes						Lightcurve ampl.			Qual. flag		Cross ID
				<i>r</i>	<i>i</i>	<i>g</i>	σ_r	σ_i	σ_g	<i>r</i>	<i>i</i>	<i>g</i>	A	R	
V001	184.61588	47.35870	7.208	25.526	25.490	...	27	45	...	275	277	...	C	A	MI095711
V002	184.73772	47.34910	7.482	24.928	24.617	...	18	20	...	211	107	...	C	A	
V003	184.63512	47.36143	7.643	24.945	25.105	25.426	15	27	19	277	197	268	C	A	
V004	184.71381	47.35652	7.862	24.740	24.493	25.215	17	20	28	315	161	478	C	A	
V005	184.64999	47.32576	8.956	24.552	24.394	25.200	09	12	14	259	138	315	C	A	
V006	184.83194	47.24321	10.278	25.060	24.311	...	13	12	...	241	135	...	C	B	MI084547
V007	184.79041	47.20185	11.212	24.609	24.553	24.756	12	18	13	287	209	283	C	A	
V008	184.70895	47.33271	11.472	24.912	24.323	25.481	18	15	32	403	208	645	C	B	
V009	184.78964	47.23041	11.827	25.212	24.913	...	18	25	...	279	295	...	C	A	
V010	184.82361	47.16617	12.068	26.026	25.050	...	37	22	...	476	293	...	B	C	
V011	184.68954	47.33534	12.493	25.094	24.704	25.815	19	20	37	339	180	396	C	A	MI122858
V012	184.64534	47.33925	12.517	25.719	25.497	26.868	30	41	83	391	365	800	B	C	
V013	184.87843	47.16182	12.716	25.721	24.951	...	23	20	...	270	266	...	B	C	
V014	184.82854	47.23107	13.132	25.910	24.989	...	45	28	...	437	331	...	A	C	
V015	184.85751	47.20291	14.208	25.670	24.833	...	26	22	...	361	297	...	A	C	
V016	184.69113	47.34583	14.379	23.985	23.590	24.761	07	08	16	355	183	673	C	B	MI043585
V017	184.73586	47.35723	15.055	24.122	23.846	24.601	08	11	12	360	191	481	C	A	
V018	184.63998	47.39553	15.526	25.553	25.201	26.565	30	30	83	486	285	407	C	C	
V019	184.75009	47.36823	16.992	25.465	24.954	...	30	27	...	656	373	...	B	C	
V020	184.74911	47.37642	18.072	25.621	25.234	...	27	27	...	380	214	...	C	C	
V021	184.64842	47.37423	19.681	25.290	24.873	...	23	26	...	424	291	...	A	C	MI117637
V022	184.65116	47.34100	19.827	25.645	24.705	...	32	18	...	675	485	...	A	C	
V023	184.69412	47.39306	19.849	25.705	24.903	...	35	22	...	555	411	...	A	C	
V024	184.69690	47.31952	19.897	25.312	24.529	...	25	18	...	304	271	...	A	C	
V025	184.72200	47.37108	19.923	24.996	24.569	26.305	19	19	62	468	314	1059	C	C	
V026	184.69537	47.34772	21.008	25.261	24.561	...	30	22	...	421	384	...	A	C	MI117637
V027	184.73750	47.36486	21.229	25.334	24.619	...	27	22	...	387	294	...	A	C	
V028	184.68947	47.33310	21.288	25.290	25.167	25.765	29	37	38	426	288	688	A	C	
V029	184.65191	47.33193	21.400	25.774	24.944	...	37	23	...	533	321	...	B	C	
V030	184.72806	47.39740	21.820	25.725	25.179	...	33	27	...	466	331	...	A	C	
V031	184.69263	47.37821	22.316	25.311	24.552	...	23	17	...	365	300	...	A	C	MI117637
V032	184.67262	47.34022	22.545	25.529	24.416	...	28	13	...	618	383	...	B	C	
V033	184.87793	47.23467	22.808	25.765	24.613	...	29	16	...	536	395	...	A	C	
V034	184.81133	47.17447	23.229	25.451	24.618	...	22	17	...	469	323	...	A	C	
V035	184.67284	47.38055	23.541	25.026	24.556	...	17	17	...	470	319	...	A	C	
V036	184.68389	47.33776	24.043	25.172	24.207	...	23	13	...	658	621	...	B	C	MI117637
V037	184.74284	47.38165	24.165	25.851	25.260	...	37	28	...	433	311	...	A	C	
V038	184.85094	47.23927	24.460	26.078	24.922	...	43	28	...	399	373	...	B	C	
V039	184.63644	47.37076	24.610	25.239	24.866	...	20	22	...	380	352	...	A	C	
V040	184.67960	47.36776	25.304	25.140	24.349	...	21	14	...	576	305	...	C	C	
V041	184.68857	47.35267	25.439	25.419	24.484	...	38	21	...	492	478	...	B	C	MI117637
V042	184.80403	47.25509	25.604	25.340	24.359	...	19	13	...	482	290	...	B	C	
V043	184.73220	47.38623	25.620	25.690	24.969	...	32	23	...	482	479	...	B	C	
V044	184.86981	47.16333	25.863	25.621	24.769	...	26	18	...	597	442	...	A	C	
V045	184.65614	47.37715	25.990	25.321	24.476	...	22	17	...	438	353	...	A	C	
V046	184.66753	47.35943	26.103	25.552	24.961	...	31	26	...	493	399	...	A	C	MI117637
V047	184.78963	47.22095	26.125	25.225	24.276	...	25	14	...	593	376	...	B	C	
V048	184.79379	47.24938	26.218	25.336	24.755	...	27	22	...	813	625	...	A	C	
V049	184.68507	47.34696	26.414	25.419	24.367	...	33	17	...	534	339	...	B	C	
V050	184.66936	47.40280	26.460	25.548	24.911	...	30	22	...	504	365	...	A	C	
V051	184.62876	47.33155	26.544	25.679	25.437	...	33	43	...	394	388	...	B	C	MI117637
V052	184.71328	47.39986	26.962	25.830	24.936	...	34	20	...	359	237	...	A	C	
V053	184.82440	47.22630	27.004	25.568	25.058	26.594	43	41	83	469	464	503	B	C	
V054	184.89491	47.23735	27.030	25.874	25.658	26.340	37	65	42	414	315	589	A	C	
V055	184.68645	47.36620	27.285	25.207	24.576	...	25	20	...	674	400	...	B	C	
V056	184.89307	47.20862	27.488	25.926	25.217	26.483	41	33	83	459	284	486	B	C	MI117637
V057	184.88348	47.19092	27.874	25.451	24.832	26.669	24	21	83	554	451	500	C	C	
V058	184.73781	47.37998	27.908	25.543	24.941	26.464	26	20	42	424	285	391	C	C	
V059	184.64410	47.35738	28.308	25.694	25.268	...	36	33	...	349	315	...	A	C	
V060	184.72662	47.36694	28.310	25.507	24.689	...	37	20	...	693	357	...	C	C	
V061	184.87186	47.22157	28.713	25.573	25.273	...	31	33	...	493	292	...	B	C	MI117637
V062	184.63959	47.35273	28.719	25.652	24.594	...	34	17	...	548	355	...	A	C	
V063	184.81345	47.20218	28.756	25.415	24.453	...	23	15	...	304	289	...	B	C	
V064	184.68690	47.39297	28.928	24.898	24.615	25.708	15	19	29	348	243	619	A	C	
V065	184.67148	47.35087	29.489	25.110	24.697	...	24	27	...	387	356	...	A	C	
V066	184.72989	47.36077	29.676	24.935	24.057	...	23	23	...	416	221	...	C	C	MI117637
V067	184.83688	47.24517	29.814	25.845	25.048	...	32	24	...	396	267	...	A	C	
V068	184.80092	47.23567	30.356	25.413	25.015	26.277	27	34	64	380	228	624	B	C	
V069	184.73583	47.38627	30.446	25.295	24.654	...	22	15	...	394	366	...	B	C	
V070	184.62962	47.37225	30.642	25.572	24.513	...	34	18	...	527	429	...	A	C	MO005461
V071	184.72589	47.37442	31.153	25.350	24.268	...	27	13	...	392	333	...	A	C	
V072	184.85495	47.16732	31.635	25.469	25.257	...	28	41	...	288	306	...	C	C	
V073	184.83421	47.22531	31.918	24.994	24.563	...	14	16	...	335	283	...	A	C	
V074	184.64639	47.32715	32.022	25.416	24.841	...	25	19	...	500	411	...	A	C	
V075	184.68745	47.35280	32.423	25.005	24.394	...	18	17	...	421	395	...	B	C	MO005461
V076	184.63246	47.38546	32.580	25.478	24.980	...	28	27	...	449	276	...	B	C	
V077	184.81525	47.23255	32.590	25.531	24.957	...	28	31	...	526	483	...	A	C	
V078	184.83374	47.17822	32.647	25.457	24.487	...	24	17	...	564	292	...	C	C	

NOTE. — Table continues in next page.

TABLE 7
NGC 4258 VARIABLES – *continued*

ID	RA (J2000) [deg]	Dec	P [d]	Mean magnitudes						Lightcurve ampl.			Qual. flag		Cross ID
				r	i	g	σ_r	σ_i	σ_g	r	i	g	A	R	
V079	184.62106	47.37893	32.837	25.656	24.960	...	31	24	...	380	266	...	A	C	
V080	184.89517	47.18497	33.105	25.605	24.966	...	27	24	...	575	384	...	A	C	
V081	184.65927	47.32368	33.983	25.621	24.912	...	29	21	...	507	255	...	C	C	
V082	184.72793	47.38604	34.048	25.542	24.977	...	24	21	...	336	304	...	A	C	
V083	184.80679	47.20128	34.145	25.624	24.862	...	27	22	...	293	310	...	C	C	
V084	184.85439	47.23996	34.444	25.706	24.869	...	27	20	...	490	277	...	C	C	
V085	184.68365	47.37157	35.174	25.502	24.527	...	31	17	...	405	302	...	A	C	
V086	184.63749	47.40559	35.394	25.719	24.726	...	37	22	...	562	560	...	B	C	
V087	184.64494	47.37695	35.451	25.284	24.662	...	24	20	...	640	424	...	A	C	
V088	184.66160	47.39078	35.709	25.770	24.746	...	37	17	...	656	343	...	C	C	
V089	184.64494	47.38647	35.849	25.049	24.232	...	17	13	...	406	284	...	A	C	
V090	184.70110	47.35960	36.192	25.074	24.417	...	20	17	...	371	300	...	A	C	
V091	184.68969	47.39113	36.433	25.437	24.605	...	22	14	...	397	267	...	A	C	
V092	184.68663	47.33139	36.508	25.433	24.782	...	26	22	...	342	363	...	C	C	
V093	184.61984	47.37281	36.735	25.439	24.734	...	25	21	...	477	472	...	B	C	
V094	184.81386	47.16805	38.094	25.583	24.845	...	23	21	...	546	444	...	A	C	
V095	184.70255	47.37877	38.311	25.853	24.964	...	43	25	...	411	348	...	A	C	
V096	184.68149	47.39181	38.560	25.817	25.487	...	39	46	...	493	466	...	B	C	
V097	184.86378	47.23680	38.681	26.018	24.848	...	40	23	...	426	440	...	C	C	
V098	184.81641	47.21674	38.810	25.520	24.635	...	33	24	...	446	434	...	B	C	
V099	184.67522	47.36093	39.948	25.114	24.564	...	20	18	...	523	491	...	B	C	
V100	184.61584	47.32947	40.331	25.954	25.296	...	44	32	...	502	306	...	B	C	
V101	184.66415	47.37246	40.684	25.328	24.431	...	26	18	...	410	226	...	C	C	
V102	184.67718	47.33715	40.812	25.766	24.544	...	39	18	...	585	474	...	A	C	
V103	184.66820	47.40309	41.746	25.201	24.434	...	18	12	...	339	254	...	A	C	
V104	184.68365	47.37054	41.820	24.890	24.301	26.008	17	14	42	450	305	416	C	C	
V105	184.73051	47.37608	42.461	25.288	24.716	...	24	20	...	314	329	...	C	C	
V106	184.68549	47.40226	43.276	24.777	24.601	...	12	17	...	361	211	...	B	C	
V107	184.81400	47.20696	43.672	25.423	24.435	...	22	13	...	370	236	...	B	C	
V108	184.62269	47.33659	43.945	25.288	24.373	...	19	12	...	325	264	...	A	C	
V109	184.80774	47.24590	44.142	25.066	24.519	...	16	17	...	469	411	...	A	C	
V110	184.70373	47.31695	44.145	24.422	24.212	...	15	17	...	355	317	...	A	C	
V111	184.74081	47.34787	44.511	24.502	23.424	...	19	09	...	400	204	...	C	C	
V112	184.64447	47.40064	44.907	25.433	24.815	...	23	19	...	335	328	...	B	C	
V113	184.82291	47.18021	44.922	25.835	25.303	...	33	33	...	490	381	...	A	C	
V114	184.70123	47.38385	46.016	25.200	24.624	...	18	17	...	241	223	...	A	C	
V115	184.83519	47.25141	48.035	25.315	24.378	...	19	12	...	395	207	...	C	C	
V116	184.64465	47.39151	50.888	25.247	24.699	...	20	17	...	368	306	...	A	C	
V117	184.72504	47.37707	50.929	25.309	24.638	...	22	17	...	389	306	...	A	C	
V118	184.88217	47.22714	51.012	25.980	25.063	...	33	23	...	517	279	...	C	C	
V119	184.81825	47.22616	51.099	25.545	24.481	...	25	15	...	353	270	...	A	C	
V120	184.64674	47.35896	51.911	25.112	24.334	...	17	13	...	248	258	...	C	C	
V121	184.71109	47.35273	52.319	24.096	23.005	...	09	05	...	328	164	...	C	C	
V122	184.62032	47.34943	52.367	24.265	24.232	24.827	07	10	10	249	182	375	A	C	
V123	184.66360	47.38593	52.458	24.904	24.302	26.090	17	15	44	351	176	316	C	C	
V124	184.83891	47.20099	52.533	24.262	23.504	25.049	12	10	21	275	184	320	B	C	
V125	184.68855	47.34049	52.755	24.561	23.996	...	12	11	...	318	235	...	A	C	
V126	184.82556	47.19948	53.460	25.424	24.285	...	22	13	...	301	215	...	A	C	
V127	184.86745	47.22917	55.180	25.278	24.449	...	17	14	...	226	152	...	A	C	
V128	184.69830	47.36268	55.865	25.140	24.366	...	27	17	...	306	213	...	A	C	
V129	184.67491	47.40297	56.694	24.691	24.115	...	11	09	...	189	175	...	A	C	
V130	184.87714	47.21610	57.464	25.414	24.782	...	20	19	...	297	271	...	A	C	
V131	184.65292	47.38004	58.623	25.592	24.807	...	30	20	...	309	185	...	B	C	
V132	184.70101	47.32054	59.136	24.425	23.261	...	13	06	...	186	124	...	A	C	
V133	184.80930	47.20495	59.640	24.919	24.399	...	15	14	...	321	197	...	B	C	
V134	184.65126	47.39195	59.895	25.515	24.875	...	25	19	...	319	265	...	A	C	
V135	184.63419	47.38253	60.243	25.304	24.379	26.284	23	14	61	305	202	256	C	C	
V136	184.82658	47.24206	62.283	24.876	24.238	...	12	11	...	209	158	...	A	C	
V137	184.62708	47.37817	62.515	25.139	24.718	...	19	19	...	290	202	...	A	C	
V138	184.64722	47.33090	62.968	25.090	24.196	...	15	10	...	226	166	...	A	C	
V139	184.67236	47.38370	63.299	25.243	24.483	...	20	15	...	322	199	...	B	C	
V140	184.70583	47.34950	63.316	24.047	23.592	...	12	11	...	150	110	...	A	C	
V141	184.64357	47.40007	64.506	25.323	24.630	26.535	20	15	62	271	230	263	C	C	
V142	184.83250	47.23988	65.440	25.818	24.753	...	30	18	...	355	203	...	B	C	
V143	184.86067	47.23750	65.990	25.091	24.653	25.915	13	16	22	180	139	253	A	C	
V144	184.79779	47.22414	66.078	24.286	23.923	24.908	08	11	13	201	183	287	A	C	
V145	184.80391	47.20254	67.656	24.283	24.069	24.995	08	12	14	188	171	217	B	C	
V146	184.85565	47.22339	68.615	23.609	22.538	25.088	03	02	12	225	142	200	C	C	
V147	184.87787	47.20903	69.116	24.513	24.129	...	10	12	...	141	111	...	A	C	
V148	184.83575	47.21942	70.386	25.432	24.841	...	27	23	...	279	192	...	A	C	
V149	184.66441	47.35379	71.945	24.941	24.683	...	16	20	...	302	209	...	A	C	
V150	184.70332	47.32773	74.032	24.618	24.171	25.285	13	12	22	195	144	326	A	C	MI091129
V151	184.80777	47.25814	74.776	24.770	24.316	25.516	11	14	17	208	182	342	A	C	
V152	184.77460	47.18651	74.875	25.404	24.840	26.510	19	18	83	382	302	320	C	C	
V153	184.61720	47.36103	77.405	24.536	24.104	25.721	10	11	23	105	108	161	C	C	
V154	184.67953	47.32811	77.785	25.349	24.598	...	22	17	...	200	201	...	C	C	
V155	184.66908	47.35049	84.354	25.223	24.508	...	23	17	...	296	179	...	B	C	
V156	184.64259	47.35006	85.781	24.864	24.189	26.295	12	12	43	176	121	241	A	C	

NOTE. — Table continues on next page.

TABLE 7
NGC 4258 VARIABLES – *continued*

ID	RA (J2000) [deg]	Dec	P [d]	r	Mean magnitudes					Lightcurve ampl.			Qual. flag		Cross ID
					i [mag]	g	σ_r	σ_i [mmag]	σ_g	r	i [mmag]	g	A	R	
V157	184.85275	47.23714	86.804	25.495	24.421	26.445	18	12	33	225	163	191	C	C	MO028606
V158	184.64136	47.40975	88.826	25.186	24.555	...	18	15	...	170	138	...	A	C	
V159	184.82123	47.23845	89.470	25.096	24.370	...	16	15	...	205	123	...	B	C	
V160	184.67403	47.36641	92.326	24.907	24.149	...	15	12	...	286	179	...	B	C	
V161	184.84747	47.22444	92.704	25.256	24.148	...	17	10	...	190	106	...	C	C	
V162	184.83473	47.25617	92.821	22.957	22.064	24.506	02	02	07	185	129	315	A	C	
V163	184.85008	47.21184	93.248	25.938	25.123	...	35	27	...	269	196	...	A	C	
V164	184.86081	47.21518	93.353	24.921	24.552	...	12	15	...	238	182	...	A	C	
V165	184.80736	47.17226	94.460	25.054	24.602	...	12	14	...	161	125	...	A	C	
V166	184.84497	47.25024	94.662	25.834	24.942	...	27	21	...	234	169	...	A	C	
V167	184.73820	47.38466	95.210	25.692	24.693	...	28	17	...	381	204	...	C	C	
V168	184.83627	47.22005	95.212	23.407	23.045	24.215	03	04	06	183	159	359	A	C	
V169	184.67161	47.33118	95.241	25.162	24.866	...	18	22	...	203	209	...	C	C	
V170	184.73251	47.32790	95.324	23.944	23.701	...	12	12	...	150	121	...	A	C	
V171	184.82220	47.18701	95.623	22.806	21.899	24.302	02	01	07	128	100	112	C	C	
V172	184.81796	47.22609	95.895	25.596	24.737	...	30	20	...	370	211	...	B	C	
V173	184.66537	47.36115	95.932	24.176	23.637	24.875	07	08	11	159	108	265	A	C	
V174	184.86279	47.16787	96.824	25.466	24.338	...	18	10	...	256	165	...	A	C	
V175	184.80141	47.25284	97.793	25.780	24.599	...	28	15	...	331	200	...	B	C	
V176	184.61964	47.37447	98.284	25.091	24.332	...	17	13	...	174	184	...	C	C	
V177	184.61723	47.33751	100.502	24.281	23.889	25.213	07	07	13	170	173	206	C	C	
V178	184.70874	47.39122	101.217	23.945	23.396	25.968	07	07	36	167	131	191	B	C	
V179	184.70857	47.34545	101.461	25.025	24.600	...	22	20	...	234	156	...	A	C	
V180	184.67085	47.36091	104.565	25.768	24.886	...	36	23	...	377	302	...	A	C	
V181	184.66515	47.36625	105.016	25.286	24.699	...	22	19	...	203	200	...	B	C	
V182	184.69290	47.39526	105.526	24.807	24.327	...	13	12	...	218	146	...	A	C	
V183	184.84706	47.17998	105.594	25.575	24.795	...	21	17	...	220	221	...	C	C	
V184	184.83070	47.20387	106.526	23.449	22.320	...	04	02	...	183	125	...	A	C	
V185	184.65627	47.36112	106.700	24.507	23.550	...	11	07	...	143	106	...	A	C	
V186	184.65965	47.34709	109.364	25.402	24.805	...	23	21	...	258	190	...	A	C	
V187	184.70140	47.35214	109.635	24.989	24.061	...	22	13	...	220	165	...	A	C	
V188	184.70262	47.35945	110.489	24.584	23.590	...	18	09	...	112	102	...	A	C	
V189	184.77916	47.20367	111.573	25.539	24.686	...	28	19	...	441	325	...	A	C	
V190	184.73289	47.38322	111.590	25.056	23.664	26.547	19	07	81	260	167	285	B	C	MI062769,F55
V191	184.71700	47.37902	111.750	24.231	23.922	25.239	09	11	21	130	106	174	A	C	
V192	184.68226	47.33691	111.814	24.723	23.680	...	17	11	...	220	115	...	C	C	
V193	184.82829	47.19758	113.580	25.193	24.484	...	17	15	...	289	234	...	A	C	
V194	184.83603	47.16718	113.615	25.079	24.652	...	14	16	...	185	108	...	B	C	
V195	184.62598	47.35208	113.660	25.495	24.596	...	24	17	...	419	254	...	B	C	
V196	184.71770	47.35175	113.819	23.650	22.539	...	07	03	...	174	109	...	B	C	
V197	184.84521	47.16626	114.106	25.438	24.471	...	21	16	...	289	277	...	B	C	
V198	184.72798	47.36155	115.726	25.516	24.546	...	29	17	...	392	334	...	A	C	
V199	184.81068	47.24450	118.645	25.226	24.637	...	17	17	...	227	200	...	A	C	
V200	184.70355	47.39479	119.050	25.560	24.674	...	25	16	...	207	154	...	A	C	
V201	184.84435	47.17062	120.160	24.544	23.484	25.963	07	05	28	284	144	285	C	C	
V202	184.71356	47.32236	120.356	22.884	22.706	23.529	05	06	07	271	200	386	A	C	
V203	184.89284	47.18734	120.719	25.721	24.999	...	28	23	...	377	298	...	A	C	
V204	184.82556	47.24960	121.079	25.546	24.720	26.672	22	17	58	372	384	400	C	C	
V205	184.86218	47.16662	121.893	25.711	24.762	...	23	17	...	242	123	...	C	C	
V206	184.73367	47.35972	121.982	24.555	24.104	...	12	12	...	178	156	...	A	C	
V207	184.81612	47.19847	124.233	25.028	24.128	...	15	10	...	196	165	...	A	C	
V208	184.70520	47.37148	127.054	25.059	24.133	...	18	12	...	242	192	...	A	C	
V209	184.86861	47.23246	127.056	25.300	24.118	...	16	09	...	245	138	...	C	C	
V210	184.82518	47.24349	127.181	25.636	24.690	...	25	17	...	258	181	...	A	C	
V211	184.82652	47.20412	128.765	25.314	24.525	...	19	15	...	236	206	...	A	C	
V212	184.81662	47.19888	130.653	25.178	23.951	...	18	10	...	302	307	...	C	C	
V213	184.83199	47.22706	135.601	25.500	24.805	...	23	21	...	271	148	...	C	C	
V214	184.61379	47.33673	138.177	22.252	21.447	23.895	01	01	04	205	108	171	C	C	
V215	184.72481	47.32247	156.980	23.823	22.794	...	10	05	...	264	175	...	A	C	

NOTE. — The uncertainties in mean magnitude reflect only the statistical component; please refer to Table 2 for systematic uncertainties. Quality flags: A, amplitude ratios; R, P-L residuals.

TABLE 8
LIGHT CURVE DATA

ID	MJD	Filter	Mag	σ	Phase
C001	3053.9805	g	25.424	57	306
C001	3053.9905	g	25.365	54	307
C001	3054.0099	r	24.642	50	310
C001	3054.0185	r	24.638	60	311
C001	3054.0272	i	24.403	84	313
C001	3054.0358	i	24.506	74	314

NOTE. — This table is available in its entirety in machine-readable form in the online version of the paper. A portion is shown here for guidance regarding its form and content.

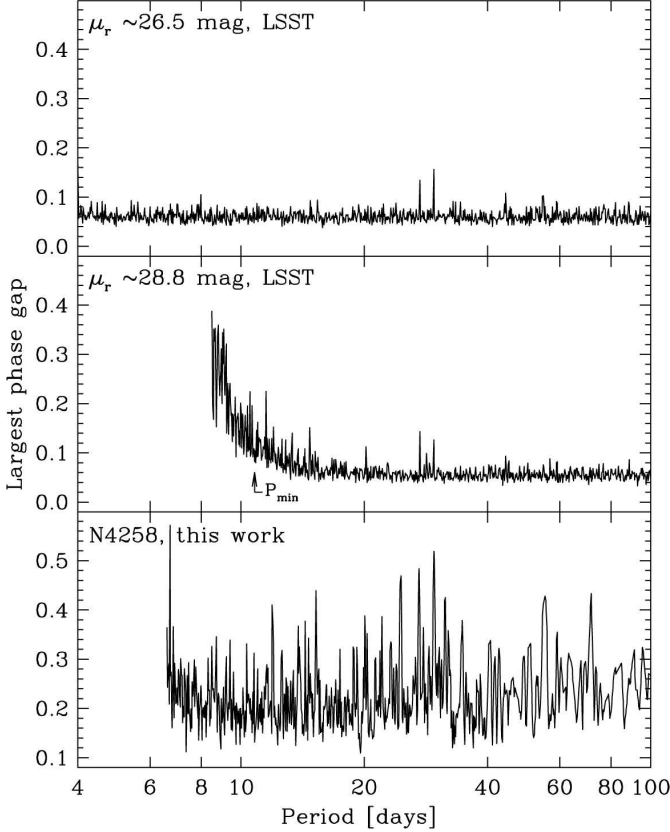


FIG. 10.— Top and middle panels: Maximum phase gap as a function of period in the light curve of Cepheids observed at the expected LSST cadence and *gri* magnitude limits, for two galaxies with apparent *r* distance moduli of 26.5 and 28.8 mag (top and middle, respectively). P_{min} indicates the period below which the maximum phase gap always exceeds the $+3\sigma$ value. Bottom panel: Same as above, but based on the cadence obtained during our survey of NGC 4258.

We used the following procedure to calculate the approximate minimum period (P_{min}) down to which we would expect complete coverage of the P-L relations of each of the galaxies listed in Table 9 in at least one of the *gri* bands. We queried the latest realization of the baseline LSST operations over a ten-year period (ops1.1140) and retrieved the Julian Date, seeing, and 5σ limiting magnitude of the simulated *gri* observations, discarding those with image quality worse than $1''$. We grouped together observations in a given band obtained on the same night into an “epoch” with the mean Julian Date and the deepest magnitude limit of an individual image

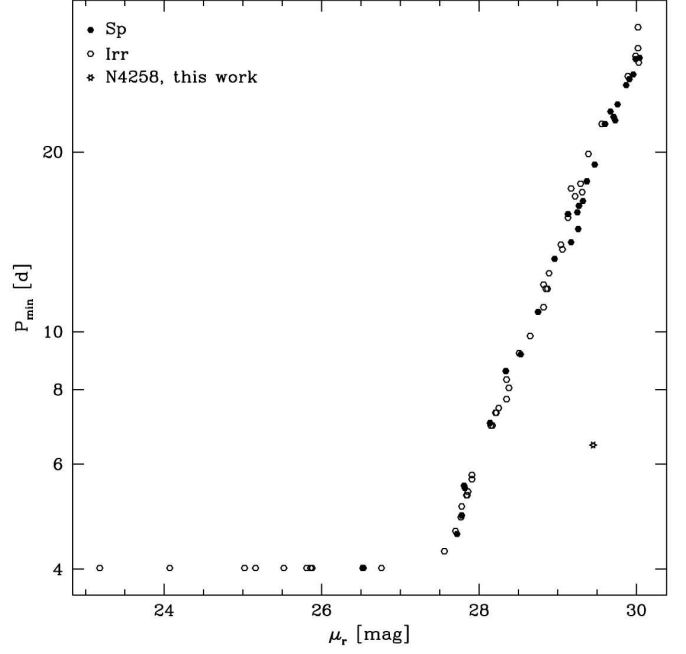


FIG. 11.— P_{min} versus distance modulus for the simulated LSST observations. Solid symbols denote spiral galaxies, while open ones represent dwarf galaxies. The star symbol shows the corresponding values for our survey of NGC 4258. LSST will deliver excellent phase coverage down to $P = 4$ d for galaxies with $D \lesssim 4.4$ Mpc ($\mu \lesssim 27.5$ mag), after which the limiting magnitude will impact the completeness of the P-L relation at the shortest periods.

(note that this is a conservative limit, since in a real analysis one would combine all images from a given night to increase the depth of the epoch). The resulting number of epochs per band, average seeing and typical 5σ limiting magnitudes are those quoted above. Next, we used the EDD distance modulus and value of Galactic extinction for the given galaxy, along with Eqns. 4-6, to calculate the faintest apparent magnitude for a Cepheid of a given period, assumed to lie $+2\sigma$ below the mean relation. We combined this information to calculate the shortest Cepheid period that would have complete P-L coverage for each epoch of observation in each band. Once this process was completed, we determined the largest phase gap that would be present in the light curve of a Cepheid of a given period, given the epochs when such a variable could have been detected (above the 5σ magnitude limit). We carried out this calculation for 10^3 trial periods equally spaced in logarithmic space for $4 < P < 100$ d. Figure 10 shows the result of this simulation for two of the galaxies, with effective *r*-band distance moduli of 26.5 and 28.6 mag, as well as the phase coverage delivered by our observations of NGC 4258. Figure 11 plots the relation between P_{min} and apparent distance modulus in *r* for all galaxies listed in the aforementioned Table.

We found that for galaxies located at $D \lesssim 4.4$ Mpc, the expected LSST cadence and magnitude depth will deliver excellent light curve coverage for all periods of interest. The largest phase gap will typically be 0.058 ± 0.01 or $\sim 4\times$ better than our Gemini observations of NGC 4258, thanks to the significantly larger number of epochs to be obtained. The limiting magnitudes of LSST will result in an increasingly larger value of P_{min} as a function of

distance for farther objects, as seen in Fig. 11. Note that this is again a conservative estimate since we were able to determine reliable periods for variables in NGC 4258 despite a typical maximum phase gap of 0.2; setting this as the limit for P-L completeness reduces $\log P_{min}$ by ~ 0.07 dex, to $P \sim 25$ d at $D \sim 10$ Mpc.

8. SUMMARY

We used GMOS on Gemini North to carry out a synoptic survey of two fields within NGC 4258 which resulted in the detection of 94 Cepheid candidates and 215 periodic variables; 262 of these were previously unknown. We derived synthetic P-L relations in the SDSS filters using the Cepheid models of Di Criscienzo et al. (2013) and found that their absolute calibration yields distance moduli that are in good agreement with the maser distance to this galaxy obtained by Humphreys et al. (2013). We investigated the prospects for surveys of extragalactic Population I & II Cepheids using the expected cadence and depth of LSST and found they bode well for a survey of suitable southern galaxies out to $D \sim 10$ Mpc.

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TABLE 9
GALAXIES SUITABLE FOR CEPHEID SEARCHES WITH LSST

PGC	RA [hms] (J2000)	Dec [dms]	μ_0 [mag]	C?	T?	Morph. type	i [deg]	Common name
143	00:01:58.2	-15:27:39	24.92 ± 0.05	✓	✓	10		WLM
621	00:08:13.5	-34:34:43	27.53 ± 0.10		✓	10		ESO349-031
701	00:09:56.3	-24:57:50	29.42 ± 0.09		✓	5	79	N24
930	00:14:03.9	-23:10:56	29.11 ± 0.10		✓	8	43	NGC45
1014	00:14:53.6	-39:11:48	26.49 ± 0.06	✓	✓	9	74	N55
2142	00:35:46.6	-25:22:27	29.84 ± 0.20			9	39	I1558
2578	00:43:03.6	-22:14:51	28.46 ± 0.10		✓	10		DDO226
2758	00:47:08.6	-20:45:38	27.73 ± 0.06	✓	✓	7	73	N247
2789	00:47:33.1	-25:17:18	27.76 ± 0.08		✓	5	76	N253
2881	00:49:21.1	-18:04:31	27.71 ± 0.08		✓	9	45	ESO540-030
2902	00:49:49.7	-21:00:47	27.65 ± 0.08		✓	10		DDO6
2933	00:50:24.6	-19:54:23	27.78 ± 0.08		✓	10		ESO540-032
3238	00:54:53.5	-37:41:04	26.48 ± 0.06	✓	✓	7	48	N300
5896	01:35:05.1	-41:26:12	27.73 ± 0.09		✓	9	72	N625
6430	01:45:03.9	-43:35:55	28.30 ± 0.10		✓	10		ESO245-005
6830	01:51:06.3	-44:26:41	23.13 ± 0.06		✓	10		Phoenix
11211	02:58:04.1	-49:22:56	28.90 ± 0.10		✓	8	66	ESO199-007
11812	03:09:38.3	-41:01:55	29.97 ± 0.20			9	60	ES300-014
12460	03:20:07.0	-52:11:09	28.59 ± 0.09		✓	9	73	N1311
13163	03:33:12.6	-50:24:51	29.10 ± 0.09		✓	9	78	I1959
13368	03:37:28.3	-24:30:05	29.90 ± 0.20			6	54	N1385
13794	03:45:54.9	-36:21:25	29.67 ± 0.20			7	71	N1437B
14475	04:06:48.9	-21:10:41	29.59 ± 0.20			8	62	N1518
14897	04:20:00.4	-54:56:16	29.10 ± 0.20			4	46	N1566
16120	04:49:55.6	-31:57:56	29.93 ± 0.20			10		N1679
16389	04:56:58.7	-42:48:02	29.21 ± 0.10		✓	8	41	ESO252-001
16517	04:59:58.1	-26:01:30	29.92 ± 0.20			7	60	N1744
16779	05:07:42.3	-37:30:47	29.79 ± 0.20			1	46	N1808
17302	05:27:05.8	-20:40:40	29.13 ± 0.10		✓	4	48	ESO553-046
18431	06:07:19.8	-34:12:16	29.92 ± 0.10		✓	10		AM0605-341
18731	06:15:54.3	-57:43:32	28.92 ± 0.10		✓	10		ESO121-020
19041	06:26:17.5	-26:15:57	29.00 ± 0.10		✓	10		ESO489-056
19337	06:37:57.1	-26:00:01	29.01 ± 0.10		✓	10		ESO490-017
26259	09:17:52.9	-22:21:17	29.71 ± 0.20			5	44	N2835
29128	10:03:06.9	-26:09:34	25.69 ± 0.06	✓	✓	9	78	N3109
29194	10:04:04.0	-27:19:55	25.64 ± 0.08		✓	10		Antlia
29653	10:11:00.8	-04:41:34	25.69 ± 0.06	✓	✓	10		SextansA
490287	10:57:30.0	-48:11:02	28.69 ± 0.10		✓	10		ESO215-009
34554	11:18:16.5	-32:48:50	29.14 ± 0.06	✓	✓	7	60	N3621
36014	11:37:53.2	-39:13:14	28.89 ± 0.10		✓	10		ESO320-014
37369	11:54:43.2	-33:33:32	28.68 ± 0.10		✓	10		ESO379-007
39032	12:13:49.7	-38:13:52	27.58 ± 0.08		✓	10		ESO321-014
42936	12:44:42.5	-35:57:60	28.68 ± 0.10		✓	10		ESO381-018
43048	12:46:00.4	-33:50:17	28.69 ± 0.10		✓	10		ESO381-020
43978	12:54:53.6	-28:20:27	28.88 ± 0.10		✓	10		ESO443-009
45104	13:03:33.2	-46:35:13	27.49 ± 0.10		✓	10		ESO269-037
45279	13:05:27.3	-49:28:05	27.85 ± 0.08		✓	6	77	N4945
45717	13:10:32.9	-46:59:31	27.87 ± 0.10		✓	10		ESO269-058
46663	13:21:47.1	-45:03:45	27.99 ± 0.10		✓	10		KK196
46938	13:25:18.5	-21:08:03	29.06 ± 0.20			3	47	N5134
46957	13:25:28.1	-43:01:05	27.82 ± 0.06	✓	✓	-2		N5128
47073	13:26:44.4	-30:21:45	28.57 ± 0.10		✓	7	66	IC4247
47171	13:27:38.4	-41:28:42	27.89 ± 0.10		✓	10		ESO324-24
48029	13:36:30.8	-29:14:07	28.67 ± 0.10		✓	10		ESO444-78
48082	13:37:00.9	-29:51:56	28.34 ± 0.07	✓	✓	5	32	M83
48334	13:39:56.0	-31:38:24	27.75 ± 0.06	✓	✓	9	64	NGC5253
48368	13:40:18.3	-28:53:39	28.19 ± 0.10		✓	10		IC4316
48467	13:41:36.7	-29:54:46	28.24 ± 0.10		✓	10		N5264
48738	13:45:01.0	-41:51:35	27.66 ± 0.10		✓	10		ESO325-11
49050	13:49:17.5	-36:03:48	27.52 ± 0.10		✓	8	37	ESO383-87
49923	14:01:21.6	-33:03:49	29.09 ± 0.20			8	54	N5398
50073	14:03:21.2	-41:22:36	28.63 ± 0.10		✓	10		N5408
51659	14:28:03.6	-46:18:19	27.79 ± 0.10		✓	10		PGC51659
62918	19:13:14.3	-62:05:19	29.23 ± 0.20			10		I4824
63287	19:29:59.0	-17:40:44	25.17 ± 0.10		✓	10		Sag DIG
63616	19:44:57.0	-14:48:01	23.41 ± 0.06	✓	✓	10		NGC6822
64054	20:03:57.3	-31:40:54	29.18 ± 0.10		✓	10		KK246
64181	20:09:31.7	-61:51:02	29.56 ± 0.20			8	77	I4951
65367	20:46:51.7	-12:50:51	25.02 ± 0.08		✓	10		Aquarius dIrr
67045	21:36:28.9	-54:33:27	29.70 ± 0.09		✓	5	78	N7090
67908	22:02:41.4	-51:17:48	26.46 ± 0.10		✓	10		I5152
68672	22:22:30.5	-48:24:14	29.52 ± 0.10		✓	10		ESO238-005
70027	22:55:45.7	-42:38:31	29.57 ± 0.20			3	43	N7412
71431	23:26:27.9	-32:23:19	26.72 ± 0.08		✓	10		UGCA438
71866	23:36:15.0	-37:56:19	29.86 ± 0.20			7	65	N7713
72228	23:43:45.1	-31:57:34	28.20 ± 0.10		✓	9	78	UGCA442
73049	23:57:49.8	-32:35:28	27.77 ± 0.07	✓	✓	7	55	N7793

NOTE. — Distance modulus & uncertainty and morphological type from Tully et al. (2013). ✓ in columns labeled “C?” and “T?” denote existing Cepheid and TRGB distance determinations. Inclination values as reported by NED, based on the $B = 26 \text{ mag}/\square''_{\text{isophote}}$.